INTRODUCTION

Finger Millet or Ragi (*Eleusine coracana*) is one of the most ancient crops in the world and still being cultivated in the arid and semi-arid tropies of Africa and Asia as a food and fodder crop. It is believed to have originated in the Highlands of Ethiopia somewhere around 3000 B.C. The cultivation and type of diversity of finger millet in Africa and India led to speculation over the time and place of its origin and domestication. Further, for a number of years, it was considered that *Eleusine indica* was a putative parent of *Eleusine coracana*. The fact that *Eleusine indica* was discovered along with *Eleusine coracana* in the debris of the excavation dating back to 1800 BC at Neolithic Sites in Mysore district of Karnataka, India gave an impetus to claim that it could have been a native of India and that *Eleusine indica* could have been a probable progenitor of *Eleusine coracana* (Hutchinson, 1965). Subsequent cytogenetical and morphological studies, however, elucidated that *Eleusine corocana* could have originated directly from *Eleusine africana* through a selection and domestication for a large grain mutant (Hilu and de Wet, 1976). This strengthened the speculation and affirmed that it was a native of Africa. It was further confirmed from the findings of the archaeological excavation in Ethiopia dating to three millennium BC. (Hilu *et al.,* 1979). It is now an established fact that *Eleusine corocana* has an African origin. And *Eleusine indica*, a diploid species with 2n=18 chromosomes, is one of the progenitors and the identity of the other donor(s) of the tetraploid *Eleusine corocana* (2n=4x=36) is still in the realm of guessing.

It is predominantly a rain-fed crop and sometimes, infrequently though, it is cultivated under irrigation. It has no particular preference to soil types; yet sandy-loams and red-loams are the best. It is a low water requirement crop and thus can grow well with a minimum rainfall between 300-400 mm. But it stands even up to 1500 mm. In India, it is generally cultivated as a *kharif* crop (rainy season crop) between June to October - November.

Finger millet production is generally net constrained pests and diseases; but the blast caused by *Magnapoartha grisae* is becoming economically important has been gaining seriousness in recent years.

Granis are generally brick-red in colour. But there are some genotypes having white or peach colored grains. The storability of grains under ambient conditions is excellent. It is, indeed, an advantage to the subsistence farmers.

Grains are tasty, ground into powder (flour) and made into a number of products. Traditionally, foods like porridge (*Uji*), stiff porridge (*Ugali*) and local brew *Busaa* are made for general consumption in Africa. However, in India, the main dishes made are Mudde (dumplings), roti (leaven bread) and porridge (*Umbli*) and in some places local brew is made for house-hold consumption.

It is a high quality energy food and its impact on human health is immense, particularly with the working class. One of the FAO reports (2005) had eulogized that: "many outsiders had marvelled at how people in Uganda and Southern Sudan could develop such a strapping physique and work as hard as they do on just one meal a day". It is attributed to energy quotient of ragi food they eat. It is true of hard working class of people in India too.

Ragi is regarded as a healthy food too. There was a popular belief in India in the past that predominantly ragi consuming population did seldom suffer from any serious illness. Most important and highly appreciated quality of ragi grain is its low glycemic index and absence of gluten in the grain that makes an ideal food for diabetic patients or those prone to diabetis, a deadly degenerative malady, which is spreading past at the global level. Further, due to low PER value (Less Protein Efficiency Rago), it is an antidote for obesity, which is another scourge causing serious health disorders in the affluent society. Presumably, it could be one of the reasons that people living in South India, a predominantly ragi consuming region, are relatively less obese. These qualities might have triggered the awareness about the virtues of ragi (finger millet) and accordingly, encouraged many countries to plan to include ragi in their diet and cropping systems in recent years.

The United States of America has already made a small beginning (FAO report, 2005). Because of those ideal qualities, the same FAO report called it a "***Super grain***".

Notwithstanding these merits, the crop had begun to lose ground, specially in Africa. FAO (2005) reported that the decline of the area planted to finger millet was so much and so fast that it was feared that it might pretty soon go into oblivion. It was predicted that in Southern Africa, Burundi, Rwanda and Zaire it might be hard to find it in a few years from now where it was a dominant cereal until recently. The fact is so scaring that it is clinging on to exist only in the plots that are grown for use on feast days and other special occasions demanding prestige fare. The obvious reason is that it was grossly neglected both from the point of view of research and development because of the competition by high yielding modern varieties of wheat, rice, maize and so on, which have received lavish funding for research in contrast to ragi / finger millet, which received none. According to Katrien Devos (2005) of the University of Georgia, USA: "the status of research on finger millet today is where it was on wheat in 1890s". Another important point to lessen the interest in ragi / finger millet is that it is more cumbersome and highly labour-oriented to produce and process relative to that of crops like wheat, rice, maize, cassava (tapioca), plantain and so on. While it was so in Africa, it was not as bad in India as it had not given in so much to yield to dominating modern varieties of cereals. For, in the first instance, the modern cereal varieties do not thrive well in arid and semi-arid areas as ragi / finger millet does, which is a latters traditional domain. Secondly, it was hard to give up ragi/ finger millet food for which the people have been accustomed to for thousands of years, if not millennia. Thirdly, research had been initiated in India as early as 1900 (Coleman, 1920) and some improved varieties and new cultivation systems had resulted from this effort, though in a small way. Consequently, the area lost during post-green revolution period, has been made up through increased productivity and production. It is true that the total cropped area in 1951-55 was 2.28 million hectares, production was 1.61 million tonnes and productivity was 740 kg/ha, while the situation in 2006-

10 period was totally different. From 1.35 million hectares, production was 1.9 million tonnes and the productivity was 1471 kg/ha. The increase in productivity over 1951-55 was overwhelmingly amounted to 104%. In the state of Karnataka, a dominant ragi / finger millet growing and consuming state, the productivity had reached a level of 2000 kg/ha and had stretched further to 3000 kg/ha in selected places.

The total area under ragi / finger millet had declined from 1.02 million hectares in 2000-01 to 0.77 million hectares in 2009-10. But the productivity had gone up beyond 1.8 tonnes per hactare in 4 out of 10 years and in one 2004-05. It had reached almost 2.00 tonnes per hactare. In experimental fields, almost 3.00 tonnes per hactare were harvested.

In Africa too, it is believed that food habits have been gradually coming back to this crop as Africans love ragi-based foods. Country governments too had initiated several programmes to resurrect the crop. In Zimbabwe, government offers attractive support price to the farmers as an incentive to produce this crop. In Kenya, markets have reacted positively and as a result, its grains sell at twice the price of sorghum and/or maize. The other countries too are equally geared up to focus on this crop. It is good, that in Uganda, finger millet / ragi maintained 50% of the total cereal area, probably due to state patronage. Strangely enough, even the subsistence farmers realised that every seed sown returned as many as 200–500 grains unlike others where it seldom crossed 100 even under ideal farming conditions. More than anything else, the other cereals have precarious chance to come up well in dry areas characterized by arid and semi-arid climates. Positive trend the crop has taken in recent years has been duly supported by the progressive state policies, could be a sign of resurgence in Africa and elsewhere, especially in India. But to sustain this growth momentum, it needs a strong Research and Developmental back up duly augmented by other public policies both in Africa and India.

This book is, however, intends to trace and highlight the research advances currently in progress at various centres around the world.

HISTORY, ORIGIN AND DISTRIBUTION

Finger millet or ragi also known as African millet *(Eleusine coracana Gaertn)* belongs to family *Poaceae*. It is a neutraceutically rich, small grained millet crop, mostly found in arid and semi-arid areas of Africa and Asia, sustaining millions of small and marginal farmers. It is a tall growing herbaceous plant with a tuft of robust root growth which enables it to endure and sustain extremely low levels of soil moisture. It has emerged as a most successful dry land crop providing succour to millions of indigent people living in relatively dry western and Lake Basin regions of Kenya and other parts of Northern and Eastern Africa and similar regions in Asia, especially in India. While its nutritionally rich grain is a staple food for humans, its straw /stovers make excellent fodder for livestock, especially for draught animals.

Grains when malted contain sweet and flavourful carbohydrates with right proportion of amino acids and make an excellent weaning foods for the infants. The protein content is, though small at 8-13%, has a high biological value with less PER (Protein Efficiency Ratio) (Vaidehi, 1986). Another interesting feature is that it has a low glycemic index with total absence of gluten in the grain, which makes it the choicest food for the people suffering from diabetes or diabetic-prone. It is one of the fastest growing scourges in the world together with much detested obesity among the younger generation (Devos, 2005)

Its nativity drew considerable attention and long and lengthy debates. And now it is finally settled in favour of Ethiopian Highlands and from here it had moved further down to South Africa on the one hand and then to India on the other, somewhere around 3000 to 4000 BC (Hilu *et al.,* 1979). But there was no empirical evidence as to when exactly it had entered India. However, Professor Sir J.B. Hutchinson in one of his books: “Essays on Crop Plants Evolution”, compiled, printed and published by the Cambridge University Press, U.K in 1965 had mentioned that few grains of finger millet along with one of its putative diploid progenitor, viz., *Eleusine indica,* were found in the charred debris in one of the Neolithic sites in Mysore district of Karnataka, India. The approximate age of these grains were reported to have been dated back to 1800 BC. Similar findings in Ethiopia (Africa) were dated to third millennium BC (Hilu *et al.,* 1979). This unequivocally established the fact that it is of African origin and from where it could have spread over to India later.

Origin

The mode of evolution of finger millet has been is still a conjecture. Decandole (1866) was the first to describe this species *Eleusine coracana* Gaertn. He proposed that India could have been the primary centre of origin. He based his observations on the ground that no ancient monument in Egypt had provided any evidence of it having ever been there. The Greeko-Roman writers, who were familiar with these regions, had never alluded to this crop in their writings. Burkil (1935), who, while in agreement with Decandole, had continued to argue in favour of Indian origin. In ancient India, it carried the name *Rajika,* which was a Sanskrit format from which the modern word Ragi could have been derived. Incidentally, Sanskrit was a widely known *lingua franka* in India of those days. Additionally, Burkil contended that it could have been a mutation product of *Eleusine indica*, a wild diploid species, widely distributed in India. While Wreath (1937) was in agreement with Burkilean view, opined that it could have migrated subsequently to Africa through Arabia and Abyssinia.

Vavilov (1951), through his extensive plant exploration studies, concluded that Abyssinia in Africa was the primary centre of origin. By contrast, Krishnaswamy and Chandola (1959) favoured two centres of origin – India and Africa. The evidence they adduced for this theory was that natural populations from both the geographical regions were similar in their pattern of diversity, cytogenetical behavior and number of dominant genes they possessed. However, Mitaru *et al.* (1994) maintained the opinion of its African origin because it was an important subsistence cereal grown in the relatively dry western and Lake Basin region of Kenya where the traditional foods like thin porridge *(Uji),* stiff porridge *(Ugali)* and local brew *Busaa* were made.

On the other hand, Mehra (1963) endorsed the Vavilovian view of Abyssinea for, the *Eleusine coracana* cultivated in India resembled the Afro-Asiatic type of *E. coracana* that was commonly found in Africa. It has short glumes enclosing bolder grains. Thus it could have been an offshoot of African highland type of *E. coracan,* which was again a derivative of *E. africana,* another tetraploid species (Kennedy O' Byrn, (1957) having not much of agricultural significance. Mehra (1963) continuing his argument further said that *Eleusine africana* and African highland types were totally absent in the whole of Indian sub-continent in as much as that they coexisted in Ethiopia (Africa) led him to conclude Ethiopian origin. And then it could have moved over to India during or slightly after Indus Valley civilization. Hence, it became ancient to India and assumed the name *Rajika.*

Yet another evidence in favour of African origin had stemmed from the fact that *E.coracana*, a tetraploid with 2n=36 chromosomes, generally cultivated in India, had cytogenetical and morphological features, which suggested that it was genetically conspecific to another tetraploid species *Eleusine africana* Kennedy O'Byrn with 2n=36 chromosomes, mostly found in Africa (Channaveeriah and Hiremath, 1974; Hilu and de Wet, 1976). Additionally, they observed that gene flow occurred freely between these two species. From this, they deduced that *Eleusine coracana* might have originated directly from *Eleusine africana,* possibly as a mutant and subsequently selected for its larger grain size and then domesticated. Purseglove (1976) identified two main types of cultivated finger millet: (a) African highland race and (b) Afro-Asiatic lowland race. Hilu and de Wet (1976) proposed that the African highland race was derived from *E. africana* and this then gave rise to African lowland race, which was then introduced into India. However, more authentic or clinching evidence that it was from East African origin came from the archeological finding of finger millet in Ethiopia by Hilu *et al.* (1979), in which the finger millet grains-like found in the debris, which were dated back to 3000 BC.

Moreover, evidence for more ancient nature of *E.coracana* to India was derived from the archeological finding of *Eleusine coracana* together with *Eleusine indica* near Halaguru, Mysore district of Karnataka, India, which were dated 1800 BC (Hutchinson, 1965). Now both the races are designated as *Eleusine coracana*, subspecies: *coracana and Eleusine coracana,* sub species*: africana* (Acheamphong *et al.,* 1974-84).

Distribution

By virtue of its outstanding food and agricultural characteristics together with excellent nutraceutical properties, it has now spread to many countries in the world. Presently, it is found in almost all the Eastern and Southern African nations such as Kenya, Uganda, Zimbabwe, Tanzania, Rawanda, Zaire, South Africa besides Ethiopia. In Asia, India is the major ragi growing country in the world. Besides, Nepal is slowly emerging as an important ragi growing country. Malaysia, Indonesia, Japan and China also figure in the ragi map of the world. Recent reports have alluded to the fact that it has made a beginning in the United States of America. But presently the grain is mostly used as bird feed.

However, in recent years, the total acreage declined drastically from 4.5 million hectares during 1951-55 to 3.8 million hectares. Severe erosion in acreage has been in Africa. Although India too had lost some acreage, it had made up with increased production and productivity. One of the FAO reports (Crop plant : ID. 5657, 2005) mentioned that in spite of the downslide in acreage, crop is not lost. It has all the positive features to stage back, if outstanding cereal science capabilities available in the world now are properly harnessed.

The grain is already nutritious with many essential amino acids like methionine and lysine, which are difficult to find generally in grain-based foods (Devos, 2005). Its highly drought resistant character combined with the low glycemic index have been excellent quality parameters that could promise optimism for its increased prospects worldwide. Further, Newman (2005) appreciated its great potential to become a speciality grain for food industry worldwide. Additionally, it is going to be a boon for the people living on subsistence economy in ecologically harsher and imbalanced dry farming zones.

In India, its distribution is practically all over the country. Even in temperate himalayas, it is being grown upto the elevation of 2,300 meters. But its concentration is in the states of Karnataka, Andhrapradesh, Tamil Nadu, Maharashtra, Odisha, Jharkand and so on. Karnataka maintains largest acreage and is a leading state in production with average yields hovering around 1.5 tonnes per hectare in general and some times touching 1.8 t/ha. (Quincunnial Report of ICAR, 2000-05). There are varieties now with a built-in yield potential from 3.0 to 4.0 t/ha. in dry lands and up to 6.0 t/ha under irrigation. These results portray the likely trajectory for its growth and development in future.

Nomenclature

Its nomenclature evokes much interest as it rings out religio-linguous overtones. Its generic name *Eleusinae* is said to have been derived from Greek Goddess of Cereals (Challam and Venkateshwarulu, 1995). But Burkil (1935) opined that it could have been named after a Greek town *Eleusi-ne*. As for its specific name, it had taken from its Ceylonese (Sri Lankan) name *Kurukkan*.

Equally interesting are its innumerable common names. The name finger millet could be obviously from the shape of the earhead, which resembled human palm and the spikes as the fingers. The name African millet represents its African origin. But *ragi* could be a colloquial transformation of its sanskrit name *Rajika*. Incidentally, sanskrit was the widely prevailing *lingua franka* in ancient India during the period when ragi was acquiring agricultural significance in India.

The other colloquial names in different countries and languages, which are synonymous have been as hereunder:

Arabia	–	Tailbon
Chinese	–	Canzi (Pinayin)
Danish	–	Fingershire
English	–	Finger millet, African millet, ragi, Koracana.
Ethiopia	–	Dagusa (Amhori Sodo), Tokuso (Amharic), Barnkiya, Oromo.
French	–	Eleusine cultivee, coracana
German	–	Fingersuire
Kenya	–	Winbic (Swahili), Kal (Dholuo), Ugimbie (Kikuyu)
Korea	–	Susu
Nepal	–	Kodo
Nigeria	–	Tamba (Hausa)
Sri Lanka	–	Kurukkan
Sudan	–	Tailbon (Arabic), Ceyut (Bari)
Tanzania	–	Mbege, Mwimbic, Wimbi, Ulegi (Swahili)
Uganda	–	Bulo
Vietnam	–	Hong mi, Cilke
Zambia	–	Kamabale, Lupoko, Mawele, Majalothi, Amale, Bule
Zimbabwe	–	Papoko, Zvio, Niere, Rukwega, Mazhovole, Uphoker, Poho

INDIA

Karnataka	–	Ragi
Andhrapradesh	–	Ragi in Telengana, Taidalu (in other parts)
Odisha	–	Mandia
Tamil Nadu	–	Kezvargu, Kaypai, Aariyam
Kerala	–	Panjapul orakooravu

Some parts of North India – Mandua

Gujarat	–	Naglee
Konkani	–	Nasne, Nachine
Maharashtra	–	Nachani, Ragee

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BOTANY AND PHYTOGEOGRAPHICAL DISTRIBUTION OF VARIABILITY PATTERN

Eleusine coracana (L) Gaertn is commonly known as finger millet or ragi belongs to the tribe P*aniceae*, family P*oaceae*, genus *Eleusine*, group C*hloridae* and species *coracana*. The genus *Eleusine* seemed to have dervied its name after Greek town *Eleusine* (Burkil 1935). However, Challam and Venkateswarulu (1965) opined that it represented the name of Greek Godess of cereals. Nevertheless, it is commonly known as finger millet since its spikes in the panicle (inflorescence) resemble the fingers of the palm. Its other name **"Ragi"** which is also common is said to have been derived from its **Sanskrit** name **'Rajika'.**

Genus *Eleusine* is a small one comprising only 11 species. The chromosome numbers in the genus ranged from 18 to 45. Since there was no species with less than 18 diploid chromosomes, it was proposed that its basic chromosome number could be x = 9. On this premise, 11 species in the genus were classified into deploids (2n = 18), tetraploids (2n = 4x = 36) and pentaploids (2n =sx = 45). The diploids are *Eleusine oligostachya* Lam*, Eleusine trystachya Lam., Eleusine jaegeri Lam., Eleusine floccfolia Linn., Eleusine borenensis Linn* and *Eleusine indica Linn*. Tetraploids are *Eleusine coracana* (L) Gaertn., *Eleusine africana Kennedy O' Byrn, Eleusine logopoides (Linn) and Eleusine verticillata* Roxb. The only pentaploid with 45 chromosomes was *Eleusine flagellifera.* It is apparent now that the species differentiation in the genus is based on the multiples of the basic chromosome number x=9. Thus there are altogether 6 diploids, 4 tetraploids and one pentaploid. It is surprising that a small genus like this could accumalate such a complex of ploidy.

Of all these species, *Eleusine coracana* was the only one, which acquired agricultural significance both in Africa and India. Its nativity (centre of origin) is now infallibly settled as Eastern Africa (Ethiopia), where it had evoloved around 3000 BC (Hilu *et al*., 1979). *Eleusine coracana* is a direct discendent of *Eleusine africana* notwithstanding the fact that, for many years, it was considered to have originated from *Eleusine indica*, a diploid with 2n = 18 chromosomes, which is distributed from Africa to eastwards Java. However, cytogenetical and morphological data indicated that *Eleusine coracana* could have originated directly from *Eleusine africana* through selection and further domestication of a larger grain mutant (Channaveeraiah and Hiremath, 1974 and Hilu de Wet, 1976).

Purseglove (1976) noticed two main cultivars of finger millet and named them as Africana highland race and Afro-Asiatic lowland race. Hilu and de Wet (1976) proposed that the high land race was derived from *E.africana* which was under cultivation and that this race then gave rise to the African lowland race, which was later introduced into India. It is now mostly grown in arid and semi-arid areas of Africa and Asia as it is highly drought tolerant.

It is a tall growing herbaceous annual with an height of a meter or so, ending with an inflorescence called umbel or panicle having finger-like spikes and hence called finger millet. It has a fibrous root system growing down to a depth of 80-90 cm with a lateral spread of around 50 cm under dry conditions. Under transplantation combined with irrigation, the depth of the root system decreased to 60-65 cm and the lateral spread to about 130-140 cm.

Ramakrishniah *et al*. (1996) evaluated and characterized 4624 accessions and found that the height of the plant ranged from 33-153 cm. The stem is compressed with nodes and thickness varies from 0.4 - 10.3 cm. It tillers profusely and they arise from the base of the plant (collar region). They vary from 1-10 per plant, but not all are productive.

Number of leaves vary according to the height of the plant. They are long and linear with a prominent midrib, which tapers into an accuminate tip. They are generally glabrous and often found with celiate margins. They are attached to the stem through a sheath, which

firmly clasps the stem right from the internode. In addition to normal leaves, there is a flag leaf, arising from the lost internode, just below the thumb (odd) finger, which is situated a few milimeters or a centimeter down from the base of the earhead. Length of the flag leaf sheath is 5.7 to 28.0 cm and the width is 0.9 to 1.1 cm. It is different from the rest of the leaves since it always remains errect unlike other leaves which are generally drooping.

The panicle (umbel) or earhead is borne on the peduncle whose length is 11.5-59.3 cm and width 11.90-15.56 mm. The main stem (culm) and tillers end up in a panicle or earhead, which consists of finger-like spikes; hence, the name finger millet. Number of fingers vary from 4-5 and some times even more. Little below the main fingers, generally there is another finger, which is known as the odd or thumb finger. The shape and size of the earhead vary. They are small, intermediate and large. They are open or fist-like, the latter due to incurved and compact fingers. Fingers consist of spikelets and are crowded into two overlapping rows on either side of the rachis. Each spikelet conatins four to five flowers (florets),. Flowers are bigger at the base than at the terminal end, the lemma is boat shaped with dark-green nerves along the median line. There is a keel with short stiff hairs. The palea encloses the ovary.

There are three stamens with short anthers and long filaments. The lobes of anthers dehisce longitudinally. There are two broad and truncated lodicules. The obovate ovary possesses a distinct style and plumose stigma. The seeds vary in colour and shape.

Seeds (grains) are covered by the glumes. But there are variations: exposed, partially covered and completely covered. Partial covering categories are more frequent. There are differences in grain colour: white, light-brown, copper-brown and purple-brown. Copper-brown types are more frequent (brick-red). Grains differ in shapes: round, reniform and ovoid. Round shaped grains are more frequent. Grain surface is either smooth or wrinkled, the former is more predominant. Thousand grain weight ranged from 2.5- 4.5 grams.

Different types of growth habits of the plant are encountered : decumbent, errect and prostrate; decumbent types are more frequent, followed by errect types. Plants are classified into pigmented or non-pigmented types. Pigmentation is localised, only seen at leaf junctions and glumes on the ears. Non-pigmented types are more frequent. Plants flower between 40-79 days and maturity ranged from 80-129 days from sowing. Lodging of the plant though common, taller plants are more susceptible.

Umashankar and Setty (1977) observed that anthers dehisce around 3.00 am and pollination takes place immediately thereafter; though self-pollination is normally expected, some amount of out-crossing is also observed. However, the latter is variety-specific (Fakrudin, 2001).

Dodke and Dhonukshe (1998) studied floral biology in 24 lines and described that the panicle had a variable number of fingers and each finger had 2 opposite rows of spikelets containing a number of florets, which are hermophrodite, except the terminal florets. There were three stamens, gynoecium is bicarpellary, unilocular and superior ovary. Two lodicules were present at the base of the ovary. There was a wide variation in respect of length of anthers, filaments, stigma and style. Anthesis occurred between 1.0-6.0 am and pollen remained viable for 20 minutes and fertility ranged from 76.92 to 100%.

Umashankar and Settey (1977) observed that the flowers opened in basipetal succession in the spikelets. In a spikelet, usually only one flower opened per day and this way it took almost a week to complete flowering in the earhead. As soon as the glume and palea began to gape, stigma and anthers emerged almost simultaneously and pollination took place immediately thereafter. Pollen remained viable only for 15-20 minutes after the dehiscence and the stigma remained receptive only for about 5 minutes after emergence out of the glumes. It was normally a self-pollinated species although some amount of cross-pollination was not ruled out. Seed is an achene.

Systematics and Phytogeographical distribution

First-ever such study was made by Coleman (1920) in Mysore state, now Karnataka in India. But this study had covered the collections endemic only to the states of Mysore (now Karanataka) and Madras (now Tamil Nadu). In spite of the collections being relatively small, he was able to recognise 7 types based on the earhead characters, glumes and grain colours. It was established that the variation was generally an interaction product, firstly of plant communities themselves in accordance with the Vavilovian law of homologous series and secondly, the plant communities and the environmental niche characteristic of the region in which they had become placed. It would, therefore, seem pertinent to examine this situation with *Eleusine coracana* since its habitat had spread over a range of geo-ecologiacal regions (Kempanna, 1975).

A total of 619 accessions were chosen from the germplasm collection for this study, from which 78 accessions were of African origin and 541 from India. They were grown for three years at Bangalore, and a three year study made of a total of 619 collections at Bangalore, had revealed the occurrence of variation not only in abundance, but also with remarkable consistency. For the clear elucidation of the pattern of manifestation of various characters in relation to geo-ecologial niches, the accessions were divided into two groups- African and Indian and studied separately (Kempanna and Govindu, 1969 a, 1969 b; Kempanna, 1975).

Study of systematics in African collections

All the 78 collections from African group were analyzed for the characters like height of the plant, number of days taken to flower, glume and grain colour, earhead shape and structure. This had revealed the existance of an array of variation in respect of each of the characters studied.

Height of the plant

The cultures divided themselves into 4 height categories:

Sl. No	Height category	Range of height in cm	No. of cultures	Percentage frequency
1.	Ver tall	More than 100 cm.	33	41.10
2.	Tall	75-99 cm	40	51.80
3.	Medium	50-74 cm	5	7.10
4.	Dwarf	Less than 50 cm	–	–

Apparently, tall and very tall cultures were in more abundance. Medium tall types were very neglegible. However, dwarf types were totally absent. This showed that the African region distinguished for the tall and very tall forms.

Flowering duration

Weeks taken for flowering pattern	No. of weeks	Percentage frequency
Early	6^{th} and 7^{th} week	6.67
Medium	8^{th} and 9^{th} week	86.66
Late (Long duration)	10^{th} and 11^{th} week	6.67

Flowering, which commenced on 58^{th} day from sowing, proceeded up to 100^{th} day. The cultures were divided into three groups: early, medium and late, and they were in different frequencies.

Medium duration types taking 8-9 weeks to flower were in majarity. Early (6^{th} - 7^{th} week) and late (10^{th} - 11^{th} week) groups were marginal in their frequencies.

Glume colour

Glume colour exhibitted differences with varying frequencies.

Sl. No.	Glume colour	Percentage frequency
1.	Purple-madder	60
2.	Cyprus-green	42
3.	Shell-pink	2.05
4.	Claret-brown	12.50
5.	Mixture of 4 and 2	2.50
6.	Mixture of 1 and 2	10.50

Obviously, the cultures were divided into 6 categories based on glume colour. Cyprus-green and Purple-madder types were predominant.

Seed colour

Seeds (grains) after maturity differed in their colour. They belonged to only two broad groups, Orient-pink and Brick-red. The latter was further divided into four sub categories: they were BR-16, BR-16/1, BR-16/2 and BR-16/3. Nearly 72% of them belonged to BR-16/2 category.

Earhead patterns/types

Considerable amount of variation could be found within earhead pattern. They differed between themselves in respect of number, shape, size, and position of spikes (fingers) as well as colour and size of the glumes. There were as many as 21 types and some of them had their sub-types too (Kempanna and Govindu 1969 a, 1969 b).

They were

Type-1 : Open earhead with 10-12 compact spikes (fingers), arranged in two to three whorls. The size of the spikes was 110-115 x 13-15 mm and had a tendency to curve inwards at the top. There was one additional spike, distinctly away from the rest at 15mm below the base of the panicle (earhead). This is generally called **thumb** finger. The twisted spikelets fully covered the ventral surface including the rachis. Glumes were purplr-madder (1028/1 of Horticultural colour chart) and hardly covered the grains. Grains before maturity were Cypurs-green (59/3). The difference between the glumes and young grains provided a nice purple-green mixture to the young panicles (earhead).

Type-2 : Open head with 7-8 in-curved spikes (fingers), arranged in two whorls. Spikes 80-90 mm in size, thumb spike at 65 mm below the base of the earhead. Twisted spikelets covered the ventral surface including the rachis. Glumes were Cyprus-green (19/3); grains were partially covered. Young grains were of Salmon colour (412/1).

Type-3 : Closed fist with 7-8 variously and irregularly twisted, very compact spikes, arranged in two whorls. Spikes were 40-45 x 12-15 mm in size and the thumb finger absent. Spikelets irregularly twisted, glumes Cyprus-green and so were young grains in colour. Grains were partially exposed.

Type-4 : Closed fist, similar to type-3. Glume colour was Purple-madder and seeds were hardly exposed. Young grains were white or peach coloured. Purple-madder glumes and whitish young grains provided an impressive whitish-purple look to the earhead.

Type-5 : Semi open head with 7-8 top incurved, compact spikes, arranged in two whorls. Spikes 85 x 13 mm in size and appeared like a question (?) mark. Spikes in second whorl were twisted and from the top appeared like a central core. Thumb spike was at 19 mm. Twisted spikelets tended to crowd more at the bottom of the spike and thus appeared like bulged earhead base. Spikelets covered the rachis and as a result, the rachis appeared to have been burried at the bottom of a deep furrow. The rim of the furrow being formed by the edge of the irregularly arranged spikelets. Glumes were Shell-pink (516/3) in colour and partially enclosed the grains, which were of the same colour before ripening.

Type- 6 : Semi-open head with 8-9 top-curved question mark like semi-compact spikes, arranged in two whorls. Spikes were 75-80 x 10-12 mm, Thumb spike at 45 mm. Spikelets were twisted and the rachis was visible. Glumes Purple-madder in colour and young grains Cyprus-green and were slightly exposed. Panicle as a whole looked Purple-madder and the seeds were not exposed.

Type-7 : Semi-open as in Types 5 and 6. Glumes were Cyprus-green and protrude prominantly. Young grains were Cyprus-green in colour and were completely covered.

Type-8 : Closed head with top-curved spikes arranged in a single whorl. Spikes at the base gave rise to sub-spikes and branching was so profuse as to form a clump at the base. Sub-spikes were irregularly twisted. Branching of the earhead was complex in which there were 6-7 main spikes and about 16 sub-spikes. Thumb spike was at 17 mm and sub-spikes appeared on the thumb spike also. Main spikes were 60-65 x 12-15 mm, sub-spikes were 20-25 x 8-9 mm. Spikes were compact, spikelets were arranged regularly and the rachis was visible. Glumes Cyprus-green and rarely protruded. Young grains were of the same colour and were well exposed. Earhead looked comparatively bigger because of the branched spikes and their crowding at certain places.

Type-9 : Closed head with 6 main spikes, arranged in a single whorl, sub-branching had confined only to the base. Thumb spike was at 30 mm and was branched. Base of the earhead looked like a big clump due to overcrowding of sub-branches at the base. Main spikes were 70-75 x 10-13 mm in size and sub-spikes were variable and were compact and irregularly twisted. Rachis was visible Glumes were Claret-brown in colour. Grains varied in their colour between Claret-brown to Cyprus-green before maturity and were partially exposed.

Type-10 : Closed head like Types 8 and 9, thumb spike absent, sub-spikes were very much twisted, but loosely. The characteristic basal clump was bigger than those in types 8 and 9. Main spikes were 85-90 x 12-14 mm and sub-spikes 30-35 x 12-14 mm. Spikelets were compact and twisted. Glumes had a mixture of Claret-brown and Cyprus-green and so were the young grains, which were partially exposed. Glumes tended to protrude, but this tendency was more pronounced at the margins. Earhead was big.

Type-11 : Closed cockscomb with 7 main spikes and indefinite number of sub-spikes, irregularly twisted. Thumb spike at 28 mm below the base of the earhead. Irregularly arranged spikelets were compact. Rachis was not visible. Glumes were Purple-madder and were slightly protruding. Young grains were Cyprus-green in colour and were slightly exposed.

Type-12 : Same as Type-11, but spikes and sub-spikes were more in number (18-20). Glumes were Purple-madder to Cyprus-green and young grains were Cyprus-green in colour.

Type-13 : It was a mixture of open and closed cockscomb with 7 main spikes and innumerable sub-spikes. The former were top-curved and the latter were irregulary twisted. Spikes were arranged in two whorls. The thumb spike at 15 mm down the base. Main spikes 60-65 x 10-13 mm and sub-spikes were highly variable and twisted. Rachis was hardly visible. Glumes were Cyprus-green and protruded. Grains were of the same colour and partially exposed.

Type-14 : Closed cockscomb head with 8-11 main spikes and a large number of irregularly curved sub-spikes, arranged in two whorls. Two thumb spikes, one at 20 mm and the other at 50 mm below the base of the head. Main spikes were 40-45 x 12-15 mm in size, sub-spikes were highly variable; spikelets irregularly twisted. Rachis not visible. Glumes Purple-madder and protruded. Grains partially exposed and were white to dull-white in colour. Essentially, it was like Type-13, but for the glume colour and two thumbs. Sub-spikes, though innumerable, had all arisen from independent bases and were twisted around. The main spikes look like coiling in shell. It has the biggest head, bigger than that of Type-13.

Type-15 : Resemble Type-13, but main spikes were top-curved and only one thumb spike at 40 mm below. Glumes Purple-madder and so were the young grains and were well exposed.

Type-16 : Open head with 4-5 lax spikes, arranged in one whorl, earhead resembled an open umbrella in which outward bending of spikes could have been compared to umbrella spokes. Thumb spike at 33 mm below. Main spikes were 130-140 x 10 mm in size. Glumes Cyprus-green and so were young grains, which were partially exposed. Largest head in the series.

Type-17 : Closed head, 4-5 top-curved, very compact spikes arranged in two whorls. Glumes and young grains were Claret-brown and the latter some times Cyprus-green. Grains were exposed. Earhead was relatively small, but the grains bigger in size and densely set. Earhead was heavy with very little chaff in it.

Type-18 : Closed head with top-curved spikes, arranged in one whorl, 30-35 x 10-12 mm in size. Thumb spike at 20 mm below. Spikes, though compact, were not as much as that of Type-17. Spikelets were twisted. Rachis hardly visible. Glumes Purplish-green and grains were Cyprus-green and partially exposed.

Type-19 : This was the smallest earhead observed in this series**.** An intermediate type between Types 17 and 18. In grain size and density, it was closer to Type-18 than to Type-17.

Type-20 : Open head with 4-5 straight lax spikes, arranged in one whorl, 60-65 x 10-11 mm in size. Thumb spike at 20 mm below, spikelets were regularly arranged, rachis was visible. Glumes long and Cyprus-green in colour and covered the grains. Grains were Cyprus-green in colour.

Type-21 : Similar to Type-20, except in having longer and narrower spikes and the glumes being Purplish-green.

Considerable amount of variation was observed with African group, particularly with reference to earhead characters. The earheads varied in size from very small as in Type-18 to a giant head as in Type-13. Length of the earhead ranged from 30-35 mm as in Type-18 to 130-140 mm as in Type-16. However, in the matter of composition, they varied from simple types as in types-20 and 21 to cockscomb types as in Types-20 and 21. Nevertheless, the common type of earhead was observed with Type-1.

Study of systematics of Indian collections

Similar systematics studies were made of a total of 541 accessions, secured from all over India, except from the State of Maharashtra. Tremendous amount of variation was found for some of the characters.

Height varied between 33 cm to 135 cm and they were grouped into four categories and percentage frequency of each of them was:

Height category	Range of height in cm	Percentage Frequency
Very Tall	More than 100 cm	30
Tall	75-79	20
Medium	50-74	40
Dwarf	Less than 50cm	10

It is evident that tall and medium tall categories together predominated in the populations. Very tall forms were also aplenty, but fell short of medium-tall forms. There were a few dwarfs too. Interesting point is that unlike in African group, all the height forms were represented here in the Indian group.

Flowering commenced as early as 5-6 weeks from sowing and continued up to 12th week. It indicated that there was a wide range of variation in the matter of days to commence flowering. Based on this character, the accessions were grouped into 5 classes and the percentage frequencies were:

Duration	No. of weeks flowering to commence	Percentage Frequency
Very early	5th week	2.20
Early	6th to 7th week	28.30
Medium	8th to 9th week	20.28
Late	10th to 11th week	47.20
Very Late	12th week and above	1.52

Nearly 97% of the accessions belonged to three main groups, early, medium and late, with the overwhelming majority of the late forms. Only a few accessions were very early and very late forms were only few.

Glumes colour also varied and they had fallen into 4 categories.

Colour Pattern	Percentage Frequency
Purple-madder	74.4
Cyprus-green	18.0
Shell-pink	6.6
Purple-madder+Cyprus-green (mixture)	1.0

Purple-madder dominated the rest to be followed, although way below, by Cyprus-green. The other two hardly made any presence.

Mature grain was generally **Brick-red** in colour. But it appeared to be a complex character presenting a mosaic of colours such as Poppy-red, Jasper-red, Orient-pink, Coral-pink, Purple-madder, French-rose, Shell-pink and Peach colour. Even Brick-red had undergone changes into BR-16/1, BR-16/2 and BR-16/3. However, Brick-red was by far the most common grain colour. The others were of small frequency.

Ear head is either open or closed (fist) type. But it appeared to be a complex of variants which were aplenty at the population level. Besides a few main types, there were several sub-types too, which were amenable for classification.

Type-1: Open earhead with 7 spikes, 160 x 8mm in size, arranged in one whorl. Arrangement of spikes resembled the spokes in umbrella. The thumb spike was at 20 mm below the base of the head. Spikelets were loose and regularly arranged. Rachis visible, glumes protruded and completely covered the Cyprus-green young grains.

Sub-type(a): Number of spikes 9, 115 x 10 mm in size, arranged in 3 whorls, thumb was at 45 mm.

Sub-type(b): Resembled Type-1(a), but the glumes on the dorsal side were purple madder and those on the ventral side were a mixture of Cyprus-green and Purple-madder. Glumes did not protrude. Young grains were partially covered by glumes.

Sub-type(c): Resembled Type-1. Spikes 120 x 5 mm in size, arranged in two whorls. Two thumb spikes arose from the common point. Glume colour was as in Type-1(b).

Sub-type(d): Open head as in Type-1. Spikes were 100 x 15 mm in size. Two thumb spikes emerged from the common base. Purple-madder glumes slightly lighter in shade on the under surface and darker on the upper surface of the spike. Young grains were Vinacean - buff in colour.

Type-2: Open head with 8 spikes 50 x 7 mm in size, arranged in two whorls, thumb spike at 25mm below the base of the earhead, spikelets were loose and regularly arranged, rachis was clearly visible. Glumes were Cyprus - green and were slightly protruding. Young grains were Cyprus-green and were completely covered by glumes.

Sub-type(a): Small openhead with only 4 spikes, 40 x 5 mm in size, arranged in one whorl. Thumb spike was 5mm below. Glumes were Purple-madder and partially covered. Vinacean-buff coloured young grains.

Sub-type(b): 8 spikes, 60 x 10 mm in size, arranged in two whorls. Two thumb spikes opposite each other and were 15mm below the base. Rachis was slightly concealed. Glumes were the same as in Type-2 (a). Young grains were as in Type -2 in respect of colour and partially exposed.

Sub-type(c): Resembled sub-type 2(b), two thumb spikes originated from the common point.

Sub-type(d): Resembled 2-(b), but had a third small thumb spike, glumes were Cyprus-green in colour.

Sub-type(e): Openhead like that of sub-type 2(a), spikes were 50 x11 mm in size, arranged in two whorls. Thumb spike absent. Rachis scarcely visible. Glumes and young grains had similar colour as in Type-2.

Type-3: open earhead with 5-6 spikes, tips curved, 50 x 10 mm in size and arranged in two whorls. Thumb spike absent, spikelets were twisted and compactly arranged. Rachis was scarcely visible. Glumes were Purple-madder in colour, slightly protruded and partially covered the Cyprus-green young grains.

Type-4: Openhead with 4-5 spikes, slightly in-curved and arranged in one whorl, 60 x 10mm in size. Thumb spike at 20mm below, spikelets were loosely arranged with slightly visible rachis. Glumes were Purple-madder and protruded. Young grains were Vinacian-buff and were covered by the glumes.

Sub-type-(a): Like Type-4, but spikes were 40 x 12 mm in size. Two thumb spikes arose from the common point at 12mm below the rest. Spikelets were compact and twisted. Rachis slightly visible. Glumes were as in Type-4. Young grains were Cyprus- green and were slightly exposed.

Type-5: Open earhead with 4-5 top-curved and in-curved spikes resembling the question(?)mark, 50 x 10mm in size and arranged in two whorls. Thumb spike absent. Spikelets were completely twisted, rachis was hardly visible. Glumes were Shell-pink and young grains were Cyprus-green and were well exposed.

Sub-type(a): Resembled Type-5, but had Purple-madder glumes and Vinacian-buff young grains partially exposed.

Sub-type(b): similar to sub-type 5(a), but glumes and young grains were Cyprus-green in colour.

Subt-ype(c): About 8 top-curved and in-curved spikes, 60 x 13 mm in size; two thumb spikes twisted around each other. Spikelets were compact and twisted. Glumes were Purple-madder and non-protruding. Young grains were Cyprus-green and were partially exposed.

Type-6: Intermediate open head like Type-5. Top-curved and in-curved question mark-like spikes, 45 x 10 mm in size and arranged in one whorl, thumb spike 18 mm below. Spikelets were loosely arranged. Rachis visible. Glumes Purple-madder and non-protruding. Young grains were Vinacian-buff and slightly exposed.

Sub-type(a): Similar to sub-type-b, thumb spike at 10mm below. Glumes protrude slightly. Cyprus-green young grains were hardly exposed.

Sub-type(b): Similar to sub type-(b), but with two thumb spikes, one at 10mm and the other at 20mm below the rest, spikelets were slightly twisted. Rachi hardly visible.

Sub-type(c): Similar to sub-type 6(b). Glumes were Cyprus-green and slightly protruding.

Type-7: Closed fist-like head with a top-curved and in-curved spikes, 45 x1.5 mm in size, arranged in 3 whorls. Thumb spike at 30mm below. Spikelets were very compact and twisted. Rachis hardly visible. Glumes were Cyprus-green and young grains were partially exposed.

Sub-type(a): Resembled Type-7, but the spikes were longer, 60 x 13 mm and arranged in two whorls. Thumb spike at 13mm below, but it was broader at the base (25mm) and narrower at the top(7mm).

Type-8: Closed fist- like with 6-7 top-curved and in-curved spikes, broad at the top and narrow at the base, 45 x 15mm in size, arranged in 3 whorls. Thumb spike absent. Spikelets were very compact and twisted. Rachis non-visible. Glumes were Cyprus-green. Grains at about ripening time became fully exposed.

Type-9: Open cockscomb head with 5 top-curved and in-curved main spikes and similar number of secondaries. Main spikes were 35 x 12mm, secondaries were 25 x 6 mm. Thumb spike at 34 mm below and branched at the bottom and they were not twisting. Spikelets were compactly arranged, rachis hardly visible. Glumes Cyprus-green and non-protruding. Cyprus-green young grains were slightly exposed.

Sub-type(a): Slightly larger than Type-9. Thumb spike present at 20 mm below. Spikelets were loose and regularly arranged. Rachis visible. Glumes Purple-madder and protruding. Cyprus-green young grains were completely closed.

Type-10: Open cockscomb earhead with about 8 main spikes and about 10 sub-spikes of 55 x 9mm and 35 x 7mm, respectively. All the mainspikes were branched and were slightly top-curved, sub-spikes were straight. Thumb spike at 20 mm below and highly branched. Spikelets were loosely arranged. Rachis visible. Glumes Cyprus-green and non-protruding. Young grains were fully exposed.

Subtype(a): Similar to Type-10, but the spikes were twisted around one another. Rachis was not visible. Glumes Purple-madder and young grains were slightly exposed.

Type-11: Closed cockscomb earhead with a number of main and Sub-spikes of irregular size, twisted. Thumb spikes were present at 28 mm below and irregularly arranged. Spikelets compact. Rachis non-visible. Glumes were Purple-madder and slightly protruding. Grains were Cyprus-green and were slightly exposed.

Type-12: Giant cockscomb earhead with 7main spikes and innumerable sub-spikes, irregularly twisted and branching. Main spikes 50-60 mm long and uniformly broad. Thumb spike present at 35mm below, irregularly branched. Spikelets were compact and twisted. Rachis visible. Glumes Cyprus-green and non-protruding. Young grains were Cyprus-green and partially exposed.

Sub-type(a): Similar to Type-12; but the glumes were Purple-madder in colour.

Among the Indian populations, there were a total of 12 main types and 19 sub-types. But the latter were distributed between the types - 1,2,4,5,6,7,8,9,10 and 12. The earheads were divided into Sub-types because, although they compared by and large with the main types, they differed in some minor characteristics, which do not lend themselves to be classified as main types.

Apparently, the Indian collections had much more variation than was reported by Coleman(1920).

This study was also said to be not exhaustive since many areas with in the sub-continent like Sri Lanka and some North-Eastern states in India, Pakistan, Bangladesh and so on were not represented. Further, many collections from Jammu and Kashmir and some other North-Eastern states did not survive for long at Bangalore climate. Thus this study could be considered as open-ended.

Comparative variability of Indian and African populations

Africa and India, from where the original material had originated, have been the two distinct geographical areas isolated for long by the great Arabian sea as the natural barrier (Kempanna and Govindu, 1968(a) and (b) and Kempanna(1975). This had naturally precluded any chances of plant migration and gene exchanges between the two regions. Further, origin of *E.coracana* and its migration from Africa into South India are a great antiquity (Mehra,1963; Hilu and de Wet, 1976 and Hutchinson, 1965). Thus it is possible that pattern of variation in indian and african populations could have been the outcome of intra-regional changes necessitated by such evolutionary forces as gene mutations, structural rearrangements of genotypes to suit the constantly changing climate and natural hybridization occurring within the populations within each region. The apparent variability expounded in both the populations studied here are presumed to have developed independently with no parellels between the two regions.

Height of the plant

Populations were divided into four height categories.

Height Category	Percentage frequency	
	African	Indian
Very tall	41.10	30.00
Tall	51.80	20.00
Medium	7.10	40.00
Dwarf	0.00	10.00

Clearly, tall and very tall forms abounded with the African group with a negligible frequency of medium-tall forms. Dwarfs were conspicuously absent. On the other hand, all the 4 categories were found within the Indian group although medium-tall forms predominated. Tall and very tall forms were also in sizeable frequency along with dwarfs too. From this, there was enough evidence that the two regions significantly differed between themselves for plant height.

When the variability patterns of the Indian collections were sub-divided and considered regionwise within India, it was apparent that there was no homogeneity within the area. The regions between 0 degree to 25 degree parallel to the north of equator consisted of tall and very tall forms more frequently; whereas those beyond 25 degree parallel had medium height forms. Further, most of the dwarfs also were found in this region. Comparatively, African region perfectly identified with the first zone in India. Incidentally, both African and Indian regions have been in the same latitude. This explained the similarities between these for variation in plant height.

Maturity Period

Variation was evident about maturity character in both the groups:

Category	Percentage frequency	
	African	Indian
Very early	0.00	2.20
Early	6.67	28.80
Medium	86.66	20.28
Late	6.67	47.20
Very Late	0.00	1.52

African group seemed to have monopolised by medium maturity forms; early and late forms were only at fringes. Very late were totally excluded. Whereas, the Indian group had all the 5 forms with late forms, however, in the lead. When early and medium forms were clubbed together, they equalled the late forms. There were some very

early and very late forms too in this group, but their frequency was far too less. Nevertheless, it demonstrated the apparent heterogeneity in adopting the different maturity forms unlike in the African region where medium duration types were most favoured.

Glume colour

There were 6 glume colours found with the African group in contrast to only 4 colours in the Indian material.

Colours Category	Percentage frequency	
	African	Indian
Purple-madder	30.00	74.40
Cyprus-green	42.20	18.00
Shell -pink	2.50	6.60
Claret-brown	12.50	0.00
Mixture of 4 & 2	2.50	0.00
Mixture of 1 & 2	10.50	1.00

There was a mosaic of glume colours with the African group although Cyprus-green and Purple -madder accounted for the most. But the Indian group was having Purple-madder as a dominant class, which was followed by Cyprus-green, though way behind the Purple-madder. On the whole, with Indian collections there were less colour categories than African collections.

Matured grain colour

There were only two major groups such as Brick-red and Orient-pink with the African material. However, Brick-red further split into 4 sub-shades. Yet pure Brick-red was the major colour. With regard to Indian collections, there were a total of 10 colours: Brick-red, Poppy-red, Jasper-red, Coral-red, Shell-pink, Orient-pink, Purple-madder, French-rose and Peach colour. Further, Brick-red was represented by three sub-shades. The important thing is that heterogeneity between the groups in respect of matured grain colour was apparent. Nevertheless, Brick-red shade appeared to be a major grain colour with both the groups.

Earhead types

Maximum variation was found with both the groups. There were a total of 21 earhead types with African material, while the Indian material was characterized by 13 Main types and 20 Sub-types. African Type-2 compared well with Indian Type-8. Whereas Types-12 and 20 of African material partially resembled Indian Types-12 and 4, respectively.

It may now be concluded that there were some similarities between the two groups in respect of certain traits and partially so with certain others. The main point, however was that Indian collections had more variability with regard to height of the plant, maturity period (duration), matured grain colour and earhead types than the African collections.

Phyto-geographical distribution of variability pattern

According to Vavilovian (1951) concept, no two geographical regions would seldom be alike in the matter of developmental patterns of their variation. So the generalized account of variation patterns is less meaningful as they often do not reflect the true characteristics of the concerned geographies as a whole unless they are broken into sub-geographical entities and reappraisal is made. Such information, if it could be available, would have a significant fundamental and practical bearing on the processes of crop improvement.

Geographical regions	Very tall	Tall	Medium	Dwarf
Kerala	0.00	40.00	53.33	6.67
Mysore (Karnataka)	38.07	29.67	32.26	-
Madras (Tamil Nadu)	60.00	34.17	5.8.3	-
Andhrapradesh	28.00	24.00	48.00	-
Odisha	76.54	16.05	7.41	-
Madhya Pradesh	5.57	16.65	77.78	-
Gujarat	-	100.00	-	-
Punjab	22.22	55.56	16.67	5.56
Jammu & Kashmir	-	33.33	66.67	-
Uttarpradesh	1.31	17.12	60.52	21.05
Bihar	0.73	6.50	76.00	16.77
West Bengal	0.00	54.55	27.25	18.20
Assam & North –east States	-	-	25.00	75.00
Sikkim	-	50.00	-	50.00
Africa	41.10	51.80	7.10	-

This kind of analysis had, however been confined to Indian situation alone due to logistical reasons. Analysis was made of only two characters, namely, plant height and number of days to flower. Data collected from the studies made on a total of 619 accessions (78 from Africa and 541 from India), grown continuously for 3 seasons at Bangalore, India, was subjected to detailed analysis.

Height is a very conspicuous character at the population level in both the groups. But its credibility is rather low as it is highly reactive to the environmental fluctuations of even the lowest magnitude. However, the averages of 3 seasons' data, although not true to the type, it was presumed to be not too far from the real values. While the states in India, which grew ragi, were taken as different regions, Africa as a whole was taken as one entity. Based on this premise, distribution of variation was scored in different geographical entities.

It is clear from the data that majority of the cultures across the regions were distributed between the tall and medium height forms, flanked on either side by very tall and dwarf forms. Pattern of distribution was not random in as much as that it followed a particular pattern such that the contiguous regions grouped together to form definite geographical regions with their own selective pattern of variation.

The regions of Africa, Karnataka, Andrapradesh and Odisha form the first zone, in which very tall and tall forms could be found in preponderance with fewer medium forms. On the other hand, the second zone, which covered the regions of Madhyapradesh, Bihar, Uttarpradesh and Jammu and Kashmir distinguished for its medium height forms, followed by dwarf and tall forms in that order. However, there were no very tall forms in the second zone. The third zone comprising the regions of Assam, Sikkim and North-Eastern states was characterized by dwarf forms with a few tall and medium forms. It was, however, predominantly a zone of dwarfs.

Additionally, there were other regions like Punjab, West Bengal and Kerala, which were not exactly aligned with any of the neighbouring regions. They maintained their own pattern. For example, Punjab region included all the four height categories. It could be assumed that very tall and tall forms found in this region were akin to those found in the first zone. To that extent, it had an affinity towards the first zone with which it was contiguous on one side. On the other side was the second zone, characterized by medium types, which could have extended to eastern side of the Punjab region comprising medium forms. The conclusion, therefore was that this region could finally merge with the first and the second major zones, respectively. On the same anology. West Bengal with all the four height forms could be merged with all the three major zones surrounding it.

Kerala region, down South-West in India, presented a peculiar pattern. Since it had a sizeable number of tall forms, first it seemed to align with the first zone, which was its immediate neighbour. Secondly, it had also had a large proportion of medium and dwarf forms put together, which was a typical characteristic of the second zone, though it was far away from the Kerala region up in the North. Thus Kerala region having no definite pattern, unlike other regions, presumably could sustain itself as a micro-centre. On similar grounds, Gujarat region with its solid tall forms could also be considered as another micro-centre.

Overall analysis of the height forms finally yielded to point out that there were three major zones and two micro-centres. The first zone with very tall and tall forms in predominance could be accounted for by the nearness to equator together wih the associated geo-ecological factors. Besides, the concentration of dwarfs in the third zone(Assam and North-Eastern states) seemed to have been the result of topographical and climatological reasons. In this complex ragi hardly had very little role to play agriculturally as well as in food habits.

The case of a micro-center in Kerala is very peculiar, for the forms in inland areas compared with the first zone, which is contiguous to it. But those forms in the coastal region (West Coast) tended to be medium and dwarf as they were constantly battered by the coastal climate, particularly South-West monsoon, which has normally been very severe. Dwarfs or the less tall forms enjoyed good evolutionary advantages under these circumstances.

Nevertheless, the case of Gujarat, which did not fall into any familiar pattern defied explanation.

Human indulgence could have played a role in shaping the variability pattern in the first zone. For, from times immemorial, finger millet played a dual role as a food and fodder crop. Fodder had been an important biproduct of finger millet on which livestock are reared, which were inseparable for an agrarian economy characteristic of this zone. Further, Mehra (1963) observed that a special kind of sieve was made in Africa out of the longer and stronger stalks of the finger millet. It was not incongruous, therefore, to believe that a strong human element had been involved in the evolution of this pattern in this zone.

Nevertheless, the position of Andhrapradesh in this zone was some what different since tall and very tall forms put together equal medium types instead of exceeding in accordance with the zonal pattern. But the point was that the state of Andhrapradesh was divided agriculturally between areas under smaller millets grown in dry lands and rice in irrigated lands. Areas under small millets were contiguous to Karnataka and Tamil Nadu region. Naturally therefore, the pattern of variation typified here was in accordance with the zonal characteristics. The medium forms, however, were from the riverine belt, where rice had been a major crop and small millets including finger millet were subsidiary food crops grown in rice fallows. Further, this area had been in the forefront of the North-East monsoon, the hazards of which had not been good for the tall and very tall forms. Hence the preference was for medium tall forms.

The second zone covering the Indo-Gangetic plains, Sub-Himalayan area and Central Indian plato region was predominanted by medium height forms. None other than geo-ecological factors could be attributed for the evolution of this pattern. Secondly, ragi had neither played a significant role in human food regimen nor as fodder for the livestock as there were other crops to depend upon for food and fodder purposes in this area.

Geographical regions	Very early	Early	Medium	Late	Very late
Kerala	-	60.00	40.00	-	-
Karnataka	-	-	16.13	83.87	-
Tamil Nadu	-	24.17	3.30	71.70	0.83
Andhrapradesh	-	4.00	8.00	88.00	-
Odisha	-	5.15	6.15	84.00	3.70
Madhya pradesh	-	55.56	44.44	-	-
Gujarat	-	100.00	-	-	-
Punjab	3.33	5.56	5.56	55.56	-
Jammu & Kashmere	-	100.00	-	-	-
Uttarpradesh	-	-	54.67	45.33	-
Bihar	60.70	30.30	9.00	-	-
West Bengal	-	9.00	63.70	63.70	18.30
Assam & North Eastern region	-	-	-	100.00	-
Sikkim	-	-	-	100.00	-
Africa	-	6.67	86.67	6.67	-

Number of days taken to flower

In general, the populations were characterized more by the late maturing types than the early ones. Very early and very late forms were fewer. In Punjab and Bihar there were high frequency of very early forms; where as, very late forms could be found in West Bengal region. But very late ones were found in the regions abuting the East Coast of West Bengal.

Inter-regional differences in respect of duration were very obvious. However, the zonal compositions here were different from those based on height forms. They were more here because many of them were monoregional unlike those related to height category.

South-Eastern part of the first zone comprising Tamil Nadu, Karnataka, Andhrapradesh and Odisha regions was habited by the late forms irrespective of the plant height. Areas above Odisha representing the third zone were predominated by dwarf-late forms. To this extent they were different from the rest of the zonal characteristics. The second zone excluding Uttarpradesh was occupied by the early forms, late

and very late forms were not found in this region. African region had distinguished for medium maturity forms. Thus 3 areas emerged as major zones with specific characteristics.

Punjab had been the region for very early and late forms. Though it showed affinity to first zone with its predominantly late forms, it had no such tendency towards the second zone (Uttarpradesh), which was in its immediate neighbourhood. Thus with its non-allighning tendency with neither of its surrounding zones, it constituted itself into a separate sub-zone or micro-center with its own illdefined pattern.

Uttarpradesh region, a drift from the original second zone, was neither like the rest of the second zone nor like Punjab region, whose variation pattern was that between medium and late forms with neither in absolute majority.

Bihar is another peculior region, though partially identified with Punjab region by having vey early forms it had absolutely no proximity with it as it had no late forms.

Kerala had all the cultures distributed between early and medium forms with the predominance of the former. This pattern was not in conformity with that of the regions–African region and the first zone surrounding it. Instead, as with its height forms, it appeared to be a replica of the second zone where early forms overwhelmed. This together with the pattern of height forms suggested that Kerala region could in some way be an offshoot of the second zone. Similarly, Bihar region with the predominance of very early forms stood distinctly from the rest of the regions in India. Could it also be taken as a drift from any of the other regions? But, from the data, it is difficult to conceive such a situation. Perhaps, it could make another micro-center like Kerala region.

Development of evolutionary patterns in regard to maturity period appeared to have been largely governed by a combination of both agro-economic and geo-ecological influences. The first zone seemed to endorse this assumption. As for example, cultivation of ragi in this region is largely under rainfed condition. This did not leave scope for the second crop. Consequently, evolution of late forms enjoyed the advantage of agricultural indifference where duration is not a matter to be serious about. Yet there were few medium and early forms too in this zone. These had been the agronomically preferred forms following the advent of irrigated farming recently and consequent shift in the cropping systems.

Concentration of early maturing forms in the second zone was a natural corollary of the nature of cultivation system prevalent in this zone. For, the early maturing forms had a better adaptation as subsidiary crops following the major crops in this zone.

Isolation of the dwarf-late forms of the third zone appeared to be due to none other than the natural geo-ecological reasons as ragi in this zone neither played a major agricultural role nor formed an integral part of food habits of the people.

African region with its medium duration forms might have suited for its cultivation pattern over there.

Occurrence of very early forms in the Punjab was as fuzzling as that of high proportion of very late forms found in West Bengal region. Similarly, Uttarpradesh region wedged, as it was, between the second zone and the Punjab sub-zone also showed the pattern of variation not in consonance with that obtaining in zones with which it was in close proximity. These three regions neither conformed to any one recognized pattern, nor offered scope at this stage to resolve the apparent deviation.

The case of Kerala was extremely interesting. While it radically differed from two of its neighbours, it simulated the pattern of second zone. On this ground, it could be considered as a micro-centre of the second zone from which though geographically it was far away. There was no plausible explanation for this situation.

Apparently, non-randomness in the distribution of variation patterns and the geographical contiguities resulting from the regional affinities

enabled the zonal classifications. Accordingly, three major zones and one microcentre could be identified on the basis of the height forms. Whereas four major zones, two sub-zones of a less defined pattern and one micro-center could be recognised based on the duration (days taken to flower). Clearly, therefore, agro-economical and geo-ecological reasons could be implicated with the formation of apparent zonal heterogeneity. However, Inter-zonal disaffinities were not so well defined in regard to maturity period in as much as it was with the height forms.

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CYTOGENETICS AND PHYLOGENY

The genus *Eleusine* of the family *Paniceae* and group *Chloridae* consists of 11 species belonging to different ploidy groups. of these, 6 are diploids with 2n=18 chromosomes such as *Eleusine oligostachya*, *Eleusine jaegeri*, *Eleusine floccifolia*, *Eleusine trystachya* and *Eleusine Indica*; *Eleusine boronensis* 4 are tetraploids with 2n=4x=36 like *Eleusine africana*, *Eleusine coracana, Eleusine logopoides* and *Eleusine verticillata* and lonely pentaploid *Eleusine flagellifera* with 2n= 5x= 45 chromosomes. The minimum and the maximum number of chromosomes in the genus being 18 and 45, the basic chromosome number is assumed to be x=9.

Out of a total of 11 species only two, i.e., *Eleusine africana* and *Eleusine coracana* acquired agricultural significance. *Eleusine africana* reported to be an African origin, being mostly grown in Kenya, Uganda, Ethiopia, Zambia and so on is famous for its long, strong and wiry stalk from which very tough and durable sieves, mats and fashionable baskets were made (Mehra, 1963). As a grain crop it was not known so well in the past. However, in recent years, high land race, one of the forms of *Eleusine africana*, is being grown in some parts of Africa for its grain for human consumption. But the low land race, another form of *Eleusine africana*, which is widely known as *Eleusine coracana* has been a dominant grain crop in Africa, India and elsewhere too in the world. According to Purseglove (1976), the low land race was an offshoot of high land race of *Eleusine africana* and the former gave rise to *Eleusine coracana*, which was picked up from the natural populations for its bolder grain mutant and later domesticated and adopted as a food and feed crop aeons ago.

Further studies revealed that both the races, i.e., African high land race and African low land race had common heritage in *Eleusine africana*, which itself was an allotetraploid, originating from a diploid *Eleusine indica* and another unknown diploid species. They are now taxonomically classified and nomenclatured as *Eleusine coracana* sub-species *africana* and *Eleusine coracana* sub-species *coracana* (Hilu and de Wet (1976).

The latter is more dominating now and known for its more nutritious grain for human consumption and stalk as a sustainable feed for the livestock. And now it is one of the reasonably good supplement to the world food grain resources.

Cytogenetics

Eleusine coracana has attracted a great deal of attention, both in terms of its origin as well as of its evolutionary course. There was a general perception that *Eleusine coracana* was a tetraploid form of *Eleusine indica*, a grassy weed, ubiquitous in its distribution endowed with diploid chromosome number of 2n= 18 (Coleman, 1920; Krishnaswamy, 1951; Mehra, 1963). Kempanna (1975) and Kempanna *et al*., (1976) had, however, made a detailed karyomorplogical studies of both the species and compared with each other to elicit any indication of them being interrelated.

Analysis of karyotype of *Eleusine coracona*

Chromosome number	Length (in microns)	Arm ratio (in microns)
1	3.090± 0.0203 Sat.	1.1074± 0.0054
2	2.975± 0.0465 Sat.	1.1071± 0.0063
3	2.890± 0.0663 Spl. Chromo.	1.1053± 0.0017
4	2.695± 0.0298	1.1026± 0.0017
5	2.630± 0.0289	1.1007± 0.0012
6	2.530± 0.0289	1.1083± 0.0014
7	2.489± 0.0416	1.1049± 0.0012
8	2.435± 0.0215	1.1029± 0.0010
9	2.390± 0.0340	1.1016± 0.0013
10	2.350± 0.0419	1.1061± 0.0013
11	2.290± 0.0419	1.1044± 0.0013
12	2.215± 0.0379	1.1036± 0.0014
13	2.200± 0.0368	1.1037± 0.0013
14	2.110± 0.0189	1.1089± 0.0009
15	2.050± 0.0275	1.1085± 0.0016
16	2.005± 0.0025	1.1005± 0.0005
17	2.000± 0.0000	1.000± 0.0000
18	1.900 ± 0.0000	1.111± 0.000

Source: Kempanna *et.al.* (1976)

It is evident that the karyotype of *Eleusine coracona* contained 18 pairs of chromosomes. All of them seemed to have been metacentric. Further, chromosomes varied in their size ranging from 1.9 to 3.1 microns. There were two satellited pairs of chromosomes and they were the longest in the complement. But they slightly differed in their size between themselves. However, the third pair was a peculiar one. The first impression of it was that it could be a telocentric chromosome. Obviously, it was not. It had a Feulgen-stained terminal knob. The primary centromere was found at a distance of 1.4 microns down the length from the terminal knob. The centromere and the terminal knob were connected to each other through a feebly-stained chromatin thread in such a way that it looked like a heterochromatic thread; but it was not since it was partially stained, which proved it was an euchromatic body, peculiar though. The other half of the chromosome was a normal euchromatic body, which was fully Feulgen- stained. The presence of such an unusual feature in the chromosome complement could not be easily discerned. Yet it was there (Fig.1)

Satish Chandra and Seetharam (1977) also confirmed the presence of such a phenomenon. But later studies by Nayar *et al.* (1978), Sathyan *et al.* (1983) and Mann *et al*. (1983) did not allude to this feature in their analysis of the chromosome complement. It was indeed a riddle. The remaining 15 pairs of chromosomes were normal although somewhat varied in their lengths between themselves. The difference between the longest and the shortest was of the order of 0.8 microns. Based on the lengths and arm-ratios they could be easily matched between their supposed homologues into 18 pairs (Fig.1).

Nevertheless, variations between the two sets of observations in karyomorphologies (Kempanna, 1969, 1975, Kempanna *et al.,* 1976 and Nayar *et al.,* 1978) still there wanting an explanation. In the former, the longest chromosome was 3.10 microns and the shortest was 1.9 microns as against 3.48 and 1.80 microns reported by the latter's study. However, this size differences could be accounted for by three factors: the experimental material could be from different sources. The one used by Kempanna *et al.* (1976) was ***Hullubele***, which was one of the most ancient variety untouched by research till then; whereas the one used by Nayar *et al.* (1978) was of the recently bred variety. Thus in the intervening breeding processes some structural changes could have occurred. Thirdly, the differential degree of spiralization of chromosomes could have also been one of the reasons. The changes in the centromeric positions could find an explanation in the third alternative.

Mann *et al*. (1983) in their mitotic studies of the material sourced from the Himalayan region had shown many more structural changes. There were some cells with chromosomes ranging from 24–36 as against the euploid chromosome number of 2n=4x=36. In pachytene and diplotene sub-stages of the Prophase, there were three pairs of chromosomes attached to nucleolus as against two pairs in the normal situations. Further, asynchronous cell divisions, anaphase bridges, laggards and other micro nuclei were also frequently observed. These differences could be explained on the basis that the experimental materials were the ones exposed for long to extreme cold conditions and other related ecological features of the hill climate in the Himalayan region.

Karyological analysis of *Eleusine indica*

Similar karyalogical studies were done of *Eleusine indica*, the supposed putative diploid parent of *E. coracana*. This species grows wildly as a weed in the cultivated crop fields, waste lands, roadsides, in wet lands and so on around Bangalore. Feulgen stained squash preparations were used for the karyotypic studies:

Karyotypic studies

Chromosome number	Length of chromosomes (in microns)	Arm-ratios (in microns)
1	2.850±0.0055 sat.	1.1025±0.0008
2	2.1890±0.0060 Special chro.	1.3222±0.0072
3	2.190±0.0068	1.1046±0.0010
4	2.130±0.0067	1.1057±0.0013
5	2.070±0.0057	1.1047±0.0014
6	2.030±0.0055	1.1061±0.0081
7	1.960±0.0065	1.1057±0.0014
8	1.885±0.0055	1.1060±0.0015
9	1.730±1.1059	1.1059±0.0015

Source: Kempanna *et al*., 1976.

Generally, chromosomes were smaller in size, ranging from 1.73 to 2.85 microns in length. There was one satellite pair, which was very small. The second one was peculiar as the one found in the karyotype of *E. coracana (Fig.2)*.

Strangely enough, Nayar *et al*. (1978) did not find this structure in the material used by them. It was possible that the experimental material they analysed might be a different biotype or an ecotype as *E. indica* was a prolific propagator and had a very wide distribution. The possible elimination of satellite pair in the course of multiplication at several stages as it did not seem to have any vital selection advantage in the genotype at the population level could be attributed to its absence.

The remaining 7 pairs of chromosomes were normal and fully Fuelgen – stained. There were practically no differences in lengths between 6 chromosome pairs and they were median – centric. However, the 7th pair was distinctly smaller in size than the rest. It was also metacentric (Ideogram). But, Nayar *et al*. (1978) found that two pairs out of 9 pairs were median centric and the others were sub-median centric.

Further, Nayar *et al*. (1978) studied the karyology of 5 diploid species and two tetraploids species including *E. indica* and *E. coracana*.

Sl. No.	Name of the species	Type of Karyotype	Length of chromosomal range (in microns)	Total chromatin length (in microns)
1	Eleusine trystachya	5M + 4 SM	2.40 – 3.40	51.12
2	Eleusine jaegeri	4M + 5 SM	1.92 – 3.30	46.74
3	Eleusine floccifolia	4 M + 5 SM	2.25-2.76	44.88
4	Eleusine boronensis	3M + 6SM	2.32 – 3.60	48.24
5	Eleusine indica	2M + 7 SM	1.04 – 2.36	29.12
6	Eleusine coracana (tetra)	12M +6 SM	1.80 + 3.48	81.00
7	Eleusine africana (tetra)	8 M + 10SM	0.88 – 2.84	68.00

Note: M=Median centric; SM=Sub-median centric

Source: Nayar *et al*. (1978)

It was clear that 3 diploid species had one satellite pair each. However, *E. boronensis*, the 4th diploid species, had two satellited pairs. Among tetraploids, *E. coracana* had two satellite pairs, while *E. africana* had 6. One of the satellited pair was the longest in *E. coracana*. Chromosomal lengths in *E. coracana* varied between 1.80 to 3.48 microns, whereas in *E. africana* it was 0.88 to 2.84 microns. In terms of total chromotin length, *E. indica* had 29.12 microns and which was the shortest of all the diploids, while *E. trystachya* with 51.12 microns was the longest. In tetraploides, *E. coracana* and *E. africana* were having 81.00 and 68.00 microns, respectively, in their total chromatin lengths.

Four out of 5 diploids had symmetrical karyotypes whereas, the 5th one *E.boronensis* was asymmetrical. All the diploids, except *E. indica* were closely related to each other and the obvious difference in their chromosome lengths could possibly be post- evolutionary modifications. Similarly, the difference between *E. coracona* and *E. africana* could be explained on the same analogy (Nayar *et al*. 1978).

Mann *et al.* (1983) reported aneuploid chromosome numbers ranging from 24-36 per cell in cultivars of *E. coracona* as against the normal 36 chromosomes. Seetharam *et al.* (1972) and Gowda and Sherif (1986) observed presence of 'B' chromosomes varying in number from one to two per cell in one of the cultivars IE. 644 from Uttarpradesh in India. As it is their vogue, they interfered with the normal meiotic processes. As per Seetharam *et al.* (1972), occurrence of 'B' chromosomes in *E. coracana* was the first report of its kind.

Meiosis

Kempanna and Setty (1969) and Kempanna *et al.* (1976) analyzed meiosis in *E. coracona* in the permanent Feulgen-stained squash preparations of anthers fixed in 1:1 acetic–alcohol. Meiosis was normal with 18 clear bivalents. Majority of the pollen mother cells had 18 ring bivalents. But in some cases, more than one rod bivalent was observed and such cells were rather high in their frequency. While it could be presumed to have been no abnormality, however, its repercussions on the overall frequency of recombinants in the succeeding generations could not be overlooked. Tetrad was a normal quartet, pollen grains were round and smooth-surfaced and readily stainable with acetocarmine or accto-orcein or both.

But Mann *et al.* (1983) reported asynchronous cell divisions with the resultant laggards and micro-nuclei. Evidently, it had reflected in certain proportion of pollen sterility. Seetharam *et al*. (1975) observed asynopsis in certain cells. It could be a case of gene mutation at the locus concerning chromosomal pairing. This abnormality had occurred in M_1 generation of the plants raised from the seeds treated with 1.5% aqueous solution of EMS for 8 hours. In this mutant, the meiosis had 5-7 loose bivalents per cell and the rest of the chromosomes in the cell remained univalents. As expected, it had produced 99% pollen sterility.

Secondary Association

Secondary association, as distinct from the primary chiasma making association, is defined as an attribute of expressing residual homology (homoeology) of the chromosomes of common discent not withstanding their remote ancestry. There is an evidence, as for example in wheat, such homoeologous bivalents tend to stay together as close as possible and oriented into certain groups more frequently than expected on the I-metaphase equatorial plate, perhaps, to express their residual affinity. However, there was no genetical implication of this phenomenon as there was no crossing over between the secondarily paired. chromosomes. But it could, to some extent, aid to trace the geneology of the concerned species.

The concept of secondary association, though profounded by Darlington as early as 1928, it had remained only as an hypothesis due to lack of mechanism to prove it practically. However, the genetic basis was proved by the use of telocentric chromosomes as markers in hexaploid wheat by Riley (1960) and Kempanna and Riley (1964).

But such facility as telocentric chromosomes as in polyploid wheats had not become available with other species including *Eleusine coracana*. Nevertheless the non-random association of bivalents constantly into certain number of groups more often than normal in the I-metaphase equatorial plate was taken as a criterion to investigate this phenomenon in *Eleusine coracana*.

With this assumption, secondary association was studied in *Eleusine coracana* by Kempanna and Setty (1969). Here a total of 18 bivalents preferentially associated into 7 bivalent groups on the I-metaphase plate in the proportion as shown hereunder:

Number of bivalent groups	5	6	7	8	9	10	11	Total number of cells
Observed	6.00	16	36.00	35.00	78.00	17.00	12.00	200
Expected	28.60	28.60	28.60	28.60	28.60	28.60	28.60	200

x^2 (6) = 126.39; P= < 0.001

Comparison of cell frequencies between 9- group class v/s frequency of the rest of the classes

	9- groups class (No. of cells)	Pooled frequency (No. of cells)	Total no. of cells	x^2 / P
Observed	78.20	122.00	200	x^2 99.54
Expected	28.60	171.40	200	P= < 0.001

It is obvious that 9-group class predominated the rest as it was determined through significant x^2 test. This signified the fact that *E. coracana* was a polyploid and the basic chromosome number of the genus was x=9. Evidently, *E. coracana* is a tetraploid.

However, what is not clear is whether it is an auto-or an allo-tetraploid. From the analysis of karyotype of *E. coracana*, it was obvious that it was not homogeneous. For, one half of the complement differed from the other half in terms of shape and size of the chromosomes. So it precludes the possibility of *E. coracana* from being an autotetraploid. On the other hand, it is an allotetraploid having two or more genomes originating from different sources.

It has been a long held perception that *E. coracana* could have been a tetraploid form of *E. indica* with 2n =18 chromosomes (Coleman, 1920, Krishnaswamy, 1951, Mehra, 1963). In order to verify this assumption, a comparative study was made of the karyotypes of both *E. coracana* and *E. indica*.

Comparison of karyotypes of *E. coracana and E. indica*

Chromosome Number	Eleusine coracana		Eleusine indica	
	Length of chromosomes (microns)	Arm ratio	Length of chromosomes (microns)	Arm ratio
1	3.090	1.1074 SAT	-	-
2	2.975	1.1071 SAT	2.850 SAT	1.1025
3	2.890	1.053 Spl. Chro.	2.890 Spl. Chro.	14.5100
4	2.695	1.1026	-	-
5	2.630	1.0070	-	-
6	2.530	1.1083	-	-
7	2.485	1.1049	-	-
8	2.435	1.1029	-	-
9	2.390	1.1016	-	-
10	2.350	1.1061	-	-
11	2.290	1.1004	-	-
12	2.215	1.1036	2.190	1.1046
13	2.200	1.1037	2.130	1.1057
14	2.110	1.1089	1.070	1.1047
15	2.050	1.11005	2.030	1.1061
16	2.005	1.1005	1.960	1.1057
17	2.600	1.000	-	-
18	1.900	1.1110	1.885	1.1060
			1.730	1.1059
Idiogram			Idiogram	

Source: Kempanna *et al.* (1976)

It was obvious that the chromosomes of *E. indica* were smaller in size than those of *E. coracana*. In both the species, the satellite chromosomes were the longest. There was only one satellite chromosome pair in *E. indica* as against two in the other. The second pair in *E. indica* (a special chromosome) was comparable to the third pair in *E. coracana*. The remaining 6 pairs of *E. indica* matched with as many of *E. coracana*. The so called special chromosome with one of its arms peculiarly structured was also found in the *E. coracana* complement. But it was represented only once. The 7th pair did not find its match in the entire complement(Fig.3).

Evidently, this special chromosome could have come from the *E. indica* genotype. It is clear now that *E. coracana* is an allotetraploid with two genomes of 9 chromosomes each. With this special chromosome being present only once and 6 chromosomes matching as many in the complement, there is enough reason to suppose that *E. indica* could have been the donor of one of the genomes in *E. coracana* (Kempanna, 1975 and Kempanna *et al*., 1976). This proved right of the earlier notions of Coleman (1920) and Krishnaswamy (1951). However, Channaveeraiah and Hiremath (1974) contradicted it since the F_1 hybrid between *E. coracana* and *E. indica* produced 27 univalents instead of 9 bivalents and 9 univalents as expected. On the other hand, the F_1 hybrid between *E. coracana* and *Eleusine africana* (another tetraploid species) showed perfect 18 bivalents during meiosis. Besides, *E. coracana* and *E. africana* morphologically resembled each other for several characters and crossed between each other freely in nature. Genetically too they were conspecific. From those considerations, they ruled out any role for *E. indica* in the evolution of *E. coracana,* and instead favoured *E. africana* as a possible progenitor.

Additionally, Hilu *et al*. (1978) studied the karyotype crosses and flavonoid patterns and based on the results, they discounted the possibility of any relationship between *E. indica* and *E. coracana*. Instead, they favoured one of the forms of *E. africana* having close affinity towards the cultivated form of *E. coracana*.

Purseglove (1976) recognized two types of *E. coracana* and designated them as an African highland race and (b) Afro-Asiatic lowland race. Hilu and de Wet (1976) proposed that the African highland race was a derivative of *E. africana*, which was under cultivation in Africa. This race could have later given rise to African lowland race, which

might have migrated towards Asia, mainly to India. These two races have now been designated as *Eleusine coracana* ssp. *coracana* and *Eleusine coracana* ssp. *africana* (Acheampong *et. al*. 1974 – 84). What is, however, important is that its East African origin has been established through Archeological findings in Ethiopia and the date of its origin was proposed to be third millenium BC (Hilu *et al*., 1979).

Phylogeny

Further investigations were carried out to find out the exact course of evolution through DNA marker analysis. Indeed, *E. coracana* was an allotraploid with two genomes of 9 chromosomes each. The inter-genomic relationship was elicited by Hilu (1995) through the application of random amplified poly-morphic DNA (RAPD) assay. From this, the allotetraploid nature of the species had been confirmed. But the genotype of ssp. *africana* did not group closely with that of the ssp. *coracana*. On the other hand, it showed higher affinities towards *E. indica*. Additionally, RAPD assay showed close genetic allegiance towards *E. trystachya* – *E. coracana* – *E. indica* group.

Hilu and Johnson (1992), Hilu (1995) continued their investigations through ribosomal rDNA analysis and found that all rDNA variants of *E. coracana* were found in the supposed direct tetraploid ancestor of *E. coracana* ssp. *africana*. Interestingly enough, both *E. africana* and *E. coracana* displayed the phenotypes found in diploid *E. indica*. It is now becoming clearer that finger millet *E. coracana* had directly originated from *Eleusine coracana* ssp. *africana* with *E. indica* as one of the genome donor. They had also opined that rDNA data were indicative that the wild and domesticated finger millet could have possibly originated as intra-specific polyploid hybrids from different varieties of *E. indica.*

Werth *et al.* (1994) hypothesized that *E. coracana* ssp. *coracana* was an allotetraploid resulting from the hybridization between *E. indica*, one of the supposed genome donors, and another unknown genome donor. In order to test this hypothesis, 16 isozyme loci, coding 9 enzymes were compared among the seven out of a diploid *Eleusine* species. From this, it became apparent that both the tetraploids, *E. coracana* ssp. *coracana* and *E. coracana* ssp. *africana* were found to have marker alleles of *Eleusine indica* at all loci. The isozyme analysis further revealed that genotypes of all the *non-indica* diploids investigated differed substantially between themselves. This was an indication that none of the diploids was likely to be the non-*indica* ancestor of *Eleusine coracana*. But the non-*indica* ancestor of the wild tetraploid *E. africana* might differ from that of the ssp. *coracana*. This had nullified the contradictory observations of Channaveeraiah and Hiremath (1974) who apparently relied on the chromosomal homologies (cytology) in the F_1 hybrids.

In-situ hybridization tests of *E. coracana* genome with genomic DNA of various diploid species studied by Bisht and Mukai (2001b) confirmed that *E. indica* was one of the genome donors to this allotetraploid species. Further, *in-situ* hybridization also showed a close relationship between diploid species: *E. indica, E. floccifolia*, *E. trystachya* and *E. intermedia* and also between these diploids and *E. coracana*. However, the common *in-situ* hybridization (GISH) signals of the genomic DNA of *E. indica* and *E. trystachya* on 15-18 chromosomes of *E. coracana* clearly indicated that these two species had a close genomic similarity. At the same time G1SH on 25-27 chromosomes of *E. coracana* with the genomic DNA of *E. intermedia* and cross *in-situ* hybridization signals of the chromosomes of *E. coracana* with the genomic DNA of *E. intermedia* and *E. indica* and *E. indica* or *E. intermedia* and *E. floccifolia* had shown that *E. intermedia* be an intermediate species between *E. indica* and *E. floccifolia*.

Bisht and Mukai (2001) also considered *Eleusine africana* as one of the possible progenitor of *E. coracana* and that G1SH enabled *E. indica* and *E. floccifolia* as A and B genome donors of *E. africana*, and they were also suggested to be the progenitors of *E. coracana*. *In-situ* hybridization of the genomic DNA of *E. indica, E. floccifolia,* *E. trystachya* and *E. intermedia* on the chromosomes of the polyploids supported the assumption that *E. africana* was the progenitor of *Eleusine coracana.*

Baired *et al*. attempted to study the possible potential for multiple origin of *E. coracana* through DNA sequence variation from the nuclear ITS and plastid trnT- F phylogenic analysis. From this it was found that annuals of *E. coracana* and *E. indica* formed a strongly supported lineage. However, the position of the third annual *E. trystachya* was inconsistent in the ITS and and trnT-F phylogenics.

Apparently, *Eleusine coracana* is an allotetraploid with two genomes A and B of 9 chromosomes each. It is fairly well understood now that *Eleusine indica* is a source of one of the genomes. But the identity of the other genome donor is yet at large despite the indication of allegians showed by several diploid spcies analyzed. To arrive at the precise conclusion, interspecific hybrids between *E. intermedia*, *E. floccifolia*, *E. trystachya* and *E. indica* were developed and cytologically analysed by Devurmath *et al*. (2005). High degree of homology was found through high frequency of bivalent pairing meiosis. But high degree of pollen sterility (8-32%) was found in the F_1 hybrids. Nevertheless, the chromosome associations obtained at diakinesis and metaphase meiosis suggested that these diploid species formed close genetic assemblage with the genus *Eleusine*. But the clear picture about the real candidate representing the other unknown genome donor among the wild diploids had not emerged.

Finally, it appeared that *Eleusine coracana* had been a direct descendent of *Eleusine africana*. The latter had two homoeologous genomes A and B. Sufficient evidence had been gathered now, both from karyomorphic and molecular marker analyses that the wild diploid species *Eleusine indica* was a possible 'A' genome donor. No such clear cut evidence had yet emerged in respect of 'B' genome donor from among the diploid species of the genus *Eleusine* studied. But there was a tendency to lean more towards *Elesine floccifolia*. However, more evidence is needed to come to the final conclusion.

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CROP PHYSIOLOGY

Finger millet or ragi is one of the major contributors to the global cereal grain resources. It is also an important dryland crop sustaining millions of people in the arid and semi-arid regions of Africa and Asia. It is predominantly cultivated under rainfed conditions. Thus, the study of physiological aspects of growth, productivity and other parameters assumes significance.

Higher productivity of the crop, among other things, demands adequate and optimum plant population. Many a time, this becomes a hostage to phenomenon of seed dormancy to begin with, which affects germination and consequently the crop yields. Whether such a phenomenon was operating in finger millet was investigated by Kalappa and Prasanna (1993). Out of 17 varieties tested, only 4 had over 80% germination after two months of harvest. As the age of the seed, advanced to 6, 7, and 8 months after harvest, there was a concomitant raise in germination percentage too. This indicated that seed dormancy was not of a big problem with this species.

Nevertheless, allelopathic effects of leaf leachates of freshly fallen leaves of some species such as *Eucalyptus globulous* was found to inhibit germination of seed besides affecting the growth of shoot and root (Padhya *et al.,* 1992). It was also supposed that there could be some other species in association with it, which could be inimical to the growth and development of *Eleusine coracana.*

Finger millet being a rainfed crop, moisture stress, often intermittent or unpredictable, is yet another cause that limits the growth and development of the crop ultimately leading to yield loss. This has further compounded by the factors like high and low temperatures and relative humidity. In semi-arid regions, germination and establishment of seedlings become acute due to inadequacy of moisture in the soil. Thus Shashidhar (1983), who made detailed study, suggested to be discrete in choosing the seeds having the properties of high rate of imbibition of water or higher seed osmotic potential coupled with higher metabolic activity leading to high growth rates.

Photosynthesis

Finger millet has a C_4 pathway of Photosynthesis. Plants with C_4 character have several distinctive anatomical, morphological, biochemical and physiological features, the most important being "**Kenz anatomy**" associated with the presence of specialized layers of cells called '**bundle sheath'** surrounding steel or vascular bundles. The functions of C_4 pathway lie in carboxylation of CO_2 into C_4 acids, malate or aspirate occurring first in the mesophyll cells, which are then transported into bundle sheath cells, where decarboxylation occurs releasing CO_2 either in the cytoplasm or mitochondria of bundle sheath.

C_4 plants are further divided into 3 types: (1) NADP-Maleic enzyme type, (2) NAD- Maleic-enzyme type and (3) Carboxy Kinase type. Finger millet is reported to belong to Maleic enzme type (Ramdas, 1975).

Ear photosynthesis in long and normal glumed finger millet

In finger millet, ear photosynlthesis has been shown to contribute 15-20% of the total plant photosynthsis and nearly 10% to the grain by dry weight. Shashidhar (1983), therefore, suggested that enhancing the contribution by the ear photo–synthesizing capacity was a worthwhile approach. Also in finger millet, nearly 65 to 83% of $^{14}CO_2$ fixed by the ear was contributed by the glumes. In long glumed genotype GE-2973, the $^{14}CO_2$ contributed by the ears was 228% and 43% over the Control Indaf.5 at anthesis, and 15 days after anthesis, respectively, in this genotype

Photosynthetic flux

Three varieties of *Eleusine coracana* were exposed to photon flux densities (PFD) between) 0-1500 micromol m-2^{s}-1. In all the

genotypes, photosynthetic rate increased with increasing PFD, and the photosynthetic pattern exhibited a more or less significant curve. The genotypes of ragi, which showed high photosynthetic rate under low light maintained this under natural light too. The photosynthetic pigments, which had higher photosynthetic rate under low light condition exhibited better absorption of light at lower wave lengths.

Genotypic variability for photosynthetic characters

The variability in carbon exchange rate per unit leaf area (PN) could be partly attributed to the differences in the stomatal conductance (gs) and Area leaf mass (ALM). The PN was positively correlated with total biomass. None of the other gas exchange traits had significant relationship with either TDM or with seed yield. ALM showed a strong positive association with PN. However, it was not correlated with either total biomass or seed yield. As a result, the use of ALM as surrogate for PN for identifying high biomass producing genotypes only had a limited value. Hence, selection for high PN would result in higher biomass production types (Desiraju, 2000).

Photoperiodic response of advanced breeding lines and cultivars under irrigated and rainfed conditions

Photoperiod response of 30 finger millet varieties studied for two seasons, early kharif and normal kharif, during 1987 showed the delay in flowering of early sown plants. This indicated that all the advanced breeding lines–pre–released and released cultivars–had a moderate to high quantitative photoperiod response (Jayaprakash *et al* ., 1992). Mean leaf area was significantly higher in the early– sown crop due to an extension of vegetative phase. Water stress induced developmental plasticity in flowering was also observed. Postponement of flowering occurred when water stress was imposed before panicle initiation in the field and the stress response varied markedly between genotypes.

Promod Kumar *et al.* (2002) studied 12 genotypes under rainfed condition during 1988 and 1989 in North-West hills of India to elicit any genotypic variation in photosynthesis and its associated parameters. Grain yield showed significant positive association with harvest index and negative association with days to maturity. Whereas the association of mean rate of transpiration, stomatal conductance, photosynthesis, leaf temperature depression, water-use-efficiency, plant height and total dry matter–with yield were not significant. Further more, significant positive association with days to maturity suggested that early maturing genotypes were required under hill environment, because the late maturing genotypes and their grain filling phase would coincide with low temperatures resulting in poor partitioning of photosynthates leading to poor grain yields.

Effect of artificial leaf loss at different growth stages on yield and yield components studied by Pradhanang (1994) revealed the loss of lower and middle leaves irrespective of the growth stage had no effect on yield. However, significant loss occurred (69%) when upper leaves were removed at heading stage and 42% at flowering stage. But the removal of all leaves at early dough stage reduced the yield by 6%. Nevertheless, flowering stage was the most vulnerable stage for the manifestation of yield loss.

Role of abscisic acid in root and shoot growth

It was established that at low water potentials, root elongation kept continuing, while the shoot completely ceased to grow at similar water potential. This was attributed to an unique contrivance to avoid excessive dehydration or water stress while tapping moisture available at lower depths of dehydrating soils. This mechanism was regulated by the presence of abscisic acid in the root (Suma *et al*., 2006). The abscisic acid accumulating capacity of two cultivars of ragi and groundnut, differing distinctly in root elongation under water stress, the root ABA content was not significantly different in water stressed plants of these cultivars although in root growth and root elongation at low psi was distinctly different. Tissue sensitivity to ABA and compartmentation under stress could influence these observed

differences in root growth in the cultivars of these two species rather than ABA accumalating capacity.

Effect of solar radiation and contribution of earhead and leaves to grain formation

Five genotypes studied during kharif and summer 1977 indicated that there was a considerable contribution by the earhead to the grain formation. This was more apparent in summer than in kharif. These differences might be due to the differences in sink capacity rather than transaloctions of metabolites. (Urs and Rama Rao, 1977).

To elicit the contribution of different leaves for grain formation, a variety A.927 of ragi was involved to retain one, two or three leaves from each tiller or retaining all the leaves in the tiller. During summer, defoliation was done at 20,30 and 40 days after germination and in kharif, it was done at 50,65 and 80 days after germination. The results revealed that the earhead weight and grain yield were decreased in early defoliation treatment (Urs and Rama Rao,1977).

Factors concerning centripetal disposition of bundle sheath chloroplasts during leaf development

Plants grown for 40 to 60 days in phytotron greenhouse at daylight temperatures of $25/18^{0}$C were NAD-maleic-enzyme type C_4 plants with centripetal arrangement of bundle sheath chloroplasts. The leaf segments were floated on solution with or without reagents, which included various growth regulators and inhibitors. Selections were made of the segments at 2 hours interval. Distribution of bundle sheath chloroplasts was observed and that they mingled later with vascular bundles and established a centripetal arrangement by 12-16 hours in control solutions. Auxins, cyclohexamide and cytohalasin-B inhibitted the disposition of bundle sheath chloroplast, while chloramphenical and colchicin had no effect (Miyake and Nakamura(1993).

Seed hardening

Response of ragi varieties to seed hardening (pre-soaking of seeds in water) was good as compared with unhardened seeds in terms of germination, plant growth and development (Rajshekar *et al.,* 1970). It was also reported that there was varietal variation in respect of this character. Varieties *Purna*, IE-817 and H_{22} did well by producing slightly higher yields (Rajshekar *et al.,*1970). Some of the plant characteristics like weight of ears also showed response. Vishwanathan *et al*. (1972) had shown that effect of pre-sowing hardening of seeds with $CaCl_2$, Ascorbic acid and BA on the germination, seedling growth in high ESP could be used to get establishment of the crop under alkali soils. The data on germaination percentage revealed that all the hardened varieties of ragi performed well under high saline conditions as compared with unhardened seeds (Urs and Krishna Sasthry, 1977).

Krishna Sasthry *et al.* (1969) used the germination capacity and seedling growth in NaCl and Manital solutions of different concentrations as a criterion for assessing drought tolerance. Further, it was shown that pre-sowing hardening and pre-treatment with kinins could induce drought tolerance. The variety *Purna*, Ro.902 and *Hamsa* were very responsive to the pre- treatment of seeds by way of less reduction in the root growth. Similarly shoot growth had also responded well to the seed hardening treatment. It also helped better establishment of the crop under saline-alkaline conditions. Seed hardening followed by the treatment with growth regulators induced better yields under saline conditions.

Standardization of seed hardening by chemicals like KCl and $CaCl_2$ and botanical acqueous extracts of *Prosophis julifera, Pongamia glabra,* and *Accacia nilotica* at different concentrations of 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0% for 4,8,12 and 16 hours had shown that seeds soaked in 1.0% KCl, $CaCl_2$ and *Pongamia* extract had given the highest percent of germination and vigour. In the variety A.404, all treatments like soaking in water, 0.25% $CaCl_2$, 100 PPM KH_2PO_4or 100 PPM Na_2HPO_4 before sowing improved grain yields relative to controls. However, the highest yield was with Na_2HPO_4 treatment (Punithavathi and Palaniswamy, 2001). Out of pre–sowing treatment of seeds in water, 1.0% $CaCl_2$ 2.0% polyethylene glycol (PEG.600), 1.0% KH_2PO_4 and 0.1 PPM brassinosteroid (BR), BR treatment gave the highest grain yield of 1990.29 kg/ha as against 1636.15 kg/ha of water treatment (control). But the yield increment due to BR was 21.64% followed by 14.26% of KH_2PO_4 and 9.6% $CaCl_2$ (Nithila *et al*., 2007). Pre-sowing treatment of 3 varieties with Na_2HPO_4 sown in upland sandy–loam soils during rainy season significantly increased the number of ear/m^2, number of fingers per ear, length of fingers, grain weight per ear, 1000 grain weight, grain yield, straw yield and nutrient uptake compared with control and water-soaked treatment. But the varieties varied in their response (Maitra *et al*., 1997).

Urs and Ram Rao (1977) studied the effect of gibberellins at the concentration of 10^{-4m} on the earheads treated immediately after anthesis of two varieties and found that one of the varieties EC.4840 did not respond to the treatment at the treatment at all. However, EC.927 showed response by way of increase in earhead weight and grain weight. Late-formed earheads showed better response than the early–formed ones. (Variation in seedling growth inhibition due to maleichydrazide treatment and consequential effect on yield and adaptability were observed.) Sensitivity of genotypes to maleichydrazide treatment and its relationship with yield and adaptability in ragi was estimated by Swarnalatha *et al.* (2008) in terms of growth inhibition index (SGI). Genotypic differences were observed in respect of SGI. Low sensitivity of ragi genotypes to MH in terms of SGI appeared to be good indicator of better adaptability to rich and poor environments, respectively. Low MH sensitivity could not be an indicator of stability of yield performance.

Effect of temperature and precipitation

Bandyopadhyay (2001) studied the effect of temperature and precipitation on yield of finger millet at higher hills of Garhwal, North-West Himalayas during 1994 and 1998. Cumulative temperature at flowering period recorded significant association among themselves and days to 50% ear emergence, while the effect of temperature and the number of rainy days at pre–flowering stages constituted significant negative association with grain yield, days to maturity and precipitation received at post-_flowering period. An increased total rainfall and number of rainy days at pre-flowering period, brought down the air-temperature, which, in turn, increased the number of days to 50% flowering, decreased physiological production capacity for effective grain growth and days to maturity as well. The number of rainy days at pre-flowering and total amount of rainfall received during the vegetative period of crop growth had inversely affected grain production. Thermal time at post-flowering period showed significant negative and positive regression coefficient values, respectively, on grain yield.

Thermal indices and prediction of growth and yield in three varieties at hills of Odisha during 1999 to 2004 studied by Sudhishree and Dass (2006) revealed that, on an average, finger millet needed 1840 growing degree days with heat-use efficiency (HUE) of 1.05 kg/ha degrees C-1 day for attaining physiological maturity. This suggested an exponential relationship and a linear relationship between heat-use-efficiency and yield and growing degree days and grain yield.

Effects of environmental stress on growth, SPAD measurement, radition efficiency and yield in two land races TZDA.01 and TZM.01 under two moisture regimes (irrigated and after drought) were studied in glass house by Maqsood and Ali (2007) at University of Agriculture, Faislabad, Pakisthan. The drought treatment was imposed at 28 days after sowing and beyond that no irrigation was given. Soil moisture had impacted both the land races. Drought reduced leaf area, dry matter accumulation, seed weight, radiation-use efficiency and yield. Leaf area index increased significantly in all the treatments between 28 and 84 days and there was sharp decline in LAI in TZM.01 both under irrigation and drought treatments. Maximum LAI values (5) in irrigated TZA-01 at 105 DAS and minimum LAI values (2) was recorded in water-stressed TZDA.01 and TZM.01 at 105 DAS. There was big difference in dry matter production at final harvest between the irrigated and water-stressed plants. Drought had significant effect on

grain yield of both the land races. The maximum grain yield of 4.88 t/ha was recorded under irrigated TZDA-01 followed by TZM-01 at 3.22 t/ha. The minimum grain yield of 1.92 t/ha was recorded in water-stressed TZM-01. Biomass was affected significantly by the drought treatment. Maximum radiation–use efficiency was recorded as 3.11g/MJ of the accumulated intercepted radiation.

Crop growth curve and dry matter production and leaf area index

Leaf area index (LAI), total dry matter production and partitioning for several growth characters such as relative crop growth rates (RGR), crop growth rate (CGR), net assimilation rate (NAR) and the dry matter upto panicle initiation stage were very low, which ranged from only 1.5 to 2.5 grams. At this stage 60% of the biomass is partitioned to the leaves. The crop growth early in the season is generally restricted because of low LAI reaching upto only 0.65 to 0.75 in most of the varieties. And this was too small to intercept a significant amount of solar radiation. Anthesis generally coincided with the maximum leaf area index (Shashidhar, 1983).

In the mid-late types (110-115 days duration), the dry matter during early grain filling stages (85 days) ranged from 140.20 g/plant and partitioning to the ears from 2.0 to 2.5 g/plant. However, there was a decline in LAI and the grain matured while the leaf area of the crop declined. At this stage, there was mobilization of reserve carbohydrates to the developing sinks.

Gerotypic differences in dry matter accumalation during post-anthesis period in six genotypes studied during kharif season, dry matter accumalation ranged from 33.3g to 54.10g per plant. The longer duration varieties had produced more dry matter in relation to early maturing varieties. However, there were differences among the genotypes in this regard.

Urs and Rama Rao (1977) observed that there was no relationship either between LAI and total dry matter or NAR and ear head weight or grain weight. Effects of different fertility levels on growth parameters were tested in five genotypes. Most of them tested showed an increase in LAI with increased fertility. In other genotypes, there was generally a decrease beyond the second level of fertility. There appeared to be an optimum fertility level for most of the genotypes, beyond which, they did not show any increase in different growth parameters. This showed that there was a genotypic difference in the response to fertility on both dry matter accumalation and grain weight.

In a study to elicit the effect of plant population density per unit area on leaf area index, dry matter accumalation and grain formation in kharif season revealed that LAI decreased with increased plant population. Also both dry matter accumulation and grain weight reduced with closer planting (Urs and Rama Rao, 1977).

Growth analysis studied by Nigam *et al.* (1988) indicated that CGR, RGR, NAR, LAI, leaf area duration (LAD), leaf area ratio, specific leaf area (SLA), leaf weight ratio (LWR) and DM production in 12 finger millets varieties determined at 15 days intervals between transplanting and harvest at 90 days after transplanting (DAT), DM production showed linear increase from transplanting until harvest. LAI, LAD and CGR increased upto 60 days after transplanting and decreased thereafter. The values for LAR and LWR decreased gradually 30 and 60 days after transplanting. Padma and Shivaraj (1990) showed that leaf area index in 4 varieties was higher in winter (4.3) than in summar (3.8). However, the variety APK.2 gave the highest grain yield and 1000 grain weight.

Studies on the influence of selected weather parameters made by Ganeshan *et al.* (1988) showed that the relationship between biomass production in ragi variety Indaf.5 and growing degree days (GDD), pan evaporation (EA) and evapotranspiration, a simple regression equation for biomass in combination with accumalated values of GDD, EP and ET for Kharif and summer seasons separately and for all the seasons pooled together. Four equations, Y= a+b log x, y= ea+ b log x and y=a+bx, where Y= biomass production in q/ha and x=GDD or EP or ET, were considered to relate biomass and the three weather parameters. The third equation was the most satisfactory, followed by 2^{nd} , 4^{th} and 1^{st}. Correlation coefficient for individual seasons, 'r' value of GDD vs fresh biomass was 0.82. Value for 'r' for EP vs biomass in individual seasons was 0.851 to 0.957 and for poolled data, it was 0.82. Correlation coefficient of dry biomass and poolled data were lower than those of fresh biomass and individual seasons, where 'r' values were similar for both DW and FW. The increase in biomass was proportional to delta 'X' and 'Y' and inversely proportional to 'X'.

Urs and Rama Rao (1977) determined in 5 genotypes the effect of solar radiation and contribution of earhead to grain formation and affirmed the association of earhead for grain formation. However, it was more in summer that in Kharif, which was reflected in the higher weight of the earhead. The apparent variations were attributed to differences in sink capacity than due to translocation of metabolites.

Dry matter accumalation and its distribution between various plant parts studied in six genotypes by Borale *et al.* (2002) indicated that dry matter accumalation depended on the rate of carbohydrate assimilation during photosynthesis. Dry matter accumulation was maximum at 70 days in leaves, 90 days in stem and at harvest in the ears. The total dry matter accumalation in all the genotypes increased linearly up to 90 days and declined thereafter. Such results would lead to identifying the high yielding genotypes based on higher dry matter production.

Relative stability of harvest index (H1) and partitioning efficiency studied by Reddy *et al.*(2004) at Bangalore under different levels of application of nitrogen, P_2O_5 and Potash indicated that biomass and grain yield increased with the increasing levels of NPK application upto 60 kg N/ha and 40kg P_2O_5/ha and 30 KgK/ha in the field experiment and NPK application upto 160:80:80 kg/ha in the pot–

culture. The harvest index remained stable across the nutrient levels and also between high and low harvest index types.

A total of 400 germplasm lines with diverse backgrounds were evaluated by Shankar *et al.* (1990) to identify the lines with higher carbon exchange rate (CER) and crop growth rate (CGR). Considerable variation was observed in respect of leaf area, biomass and all the growth and yield attributes. The range of stomatal frequency was relatively lower and differences in stomatal number were attributed to differences in leaf area. Since total DM was a primary criterion for achieving higher grain yield, genotypes differing in LA:DM ratios, but with similar DM and harvest index were chosen from among high biomass types. Gas exchange characteristics studied in 6 genotypes from each of the high and low LA:DM groups, which showed stability across environments, the CER in low LA:DM type was 45% higher than that of high LA:DM types. CER was correlated with LA:DM ratio (r=-0.87). High CER and CGR types of plants with high CGR and low plant conductance types were preferable.

Effect of bio-regulators

The role of bio-regulators on the growth, nutrient utilization efficiency and yield of 5 finger millet varieties was investigated by Sujatha and Rao (2003). GA_3 at 100 ppm concentration and Cycocel (CCC) at 500 ppm were sprayed at 15, 30 and 45 days after transplanting seedlings. GA_3 and CCC increased the total dry matter and leaf area index, respectively. Variety *Sapthagiri* treated with CCC had significantly higher total chlorophyll at 45 and 65 days after transplanting , while PPR.2679 did so at maturity. Variety *Padmavathi* at 60 DAT and maturity had the highest value for nitrate reductase activity with CCC. The highest NPK utilization efficiency was 38.8, 24.4 and 33.7% higher with CCC than with control, while GA_3 gave 38.6, 38.9 and 55.1% higher values, respectively. A significantly high nitrogen utilization efficiency was recorded with *Padmavathi* treated with CCC. Higher values for P and K utilization efficiencies were recorded with *Padmavathi* and *Sapthagiri*, respectively, with GA_3 treatment. Ga_3 and CCC significantly increased the yield at 22.7 and 20.9% higher than control due to increase in ear length and ear weight with GA_3 and the number of productive tillers, fingers per panicle and harvest index with CCC.

Two varieties were sprayed with ethrel (ethepon)at 1000 ppm or NaCl before harvesting in order to manipulate maturity. Both the chemicals showed desication, uniformity in maturation and gave grain yields of 2.84 and 2.97t/ha, respectively, compared with 2.58 t/ha of control. However, yields decresed by spraying with 7.5% NaCl. Crops grown with 2 or 4 seedlings per hill gave yields of 3.75 and 3.10 t/ha, respectively. However, there was no increase in yields due to chemical sprays during winter season, which implied that chemical had no effect on yield. But yields were higher with two seedlings per hill than with 4 seedlings (Desing *et al.,*).

Effect of gibberellin on earhead and grain weight was studied during summar in two genotypes of ragi (Urs and Rama Rao, 1977). GA_3 used at 10^{-4M} concentration and ear heads were treated immediately after anthesis. The result was that there were differential responses of genotypes. EC.4840 did not respond to GA_3 treatment, whereas IE.927 gave an increase in ear head weight. Late formed ear heads showed a better response than the early formed ear heads.

Sensitivity of genotypes to Maleic hydrazide treatment and its relationship with yield and adaptability was estimated in terms of seedling growth inhibition index (SGI) (Swarnalatha *et al*., 2008). Ragi genotypes showed wide differences in their sensitivity to MH in terms of SGI. Low sensitivity of ragi genotypes to MH appeared to be a good indicator of high yielding ability of genotypes. Also low MH sensitivity of genotypes could not be considered as indicators of stability in yield performance.

Nitrate reductase activity

While studying the genotypic variation in nitrate reeductase activity, nitrate flux and reducing sugars, Nataraju *et al.* (1990) found that leaf nitrate reductase (NR) activity was measured in 24 genotypes every 15 days after flowering. Whereas leaf reducing sugars and nitrate flux (nitrate concentration in xylum exudates from plants cut at 2 cm above ground) were measured 44 and 60 days after sowing. The seasonal mean leaf nitrate reductase (NR) activity ranged from 2.94 to 6.07 mmols NO<sub>2C/h per gram fresh weight in varieties ROH_2 and HR.374, respectively. NR activity decreased during growth at different rates between genotypes. Nitrate flux varied between genotypes and values were higher at 44 DAS than at 60 DAS. Leaf reducing sugars also decreased during growth.

Changes in total chlorophyll nitrate reductase, catalase and peroxidase activities in seedlings in response to nitrogen application were studied by Manoranjan Kar *et al*. (1994). Varieties, *Neelanchal* and MTU.18 (OUAT.2) were given 0-40kgN/ha. N application increased chlorophyll concentration. Nitrate reductase and peroxidase activites in leaves increased, but catalase activity decreased with increasing N rate. However, the changes in these parameters were more pronounced in the variety *Neelanchal* than in MTU.18.

Yadav *et al.* (1999) studied the effect of potassium under moisture-stress conditions in pot-culture experiment to determine the role of applied potassium on the physiology of the crop. The available potassium of the soil was 88 ppm and the applied potassium treatments were: 0, 30,60 and 90 ppm. The crop was irrigated in 4 schedules: control, 85-90%; S_1-65-70%; S_2-45-50% and S_3 -25-30% field capacity, water stress reduced the relative water content, osmatic potential, nitrate reductase activity and grain yield, but proline and stomatal resistance increased. Application of 30 ppm K under control and S_1 and 60ppm under S_2 and S_3 levels mitigated the adverse effect of water stress and finally increased the grain yield.

Seeds were treated with chlorophynyl urea (florochlor-fennson CPPU), potassium chloride (KCL), KCl+$CaCl_2$ on leaf area index (LAI), chlorophyll stability index (CSI) proline content, biomass and yield in three varieties, CO13, PR.202 and Indaf.9 (Kalarani *et al*., 2001) to find out the effect of seed treatments. Normal sowing was done on 15th July and the late sowing on 25th August. Late–sown crop exhibited reduction in LAI and CSI and increase in proline in the seedlings in all the cultivars. KCL+ $CaCl_2$ considerably improved LAI and CSI (3.9 and 84.3% in CO.13; 3.3 and 82.45% in PR.202; and 3.2 and 78.4% in Indaf.9). Stress caused accumulation of proline content KCl+$CaCl_2$ had the greatest effect for reducing proline content in late-sown crop. KCl+$CaCl_2$ treated plants showed increase in yield of 19.6% in C013; 17.5% in PR.202 and 13.9% in Indaf.9 over control.

Effect of drought on crop yields

Ragi is predominantly a dryland crop. Long spells and intermittent moisture stresses have been the major causes determining the yield and the economic prospects of the crop. According to a study, drought stress caused the loss in yield more than that from the combined effect of all other abiotic stress factors, because the magnitude of drought had been often compounded by high temperatures and low relative humidities. Analysis of rainfall distribution pattern indicated that drought stress might occur either during the stage of growth or during panicle development and anthesis.

Detailed studies revealed that some of the major factors limiting the yields had been seedling emergence and establishment, stress during vegetative phase and stress during panicle emergence stage (Shashidhar, 1983). In semi-arid regions, establishment of seedlings became acute because of inadequacy of soil moisture leading to failure of seedlings to survive. It was further observed that osmotic potential of seeds from the stressed plants was significantly higher when stress occurred during panicle development and early grain filling stages.

Germinability and seedling vigour of the stressed plants were higher. Seeds of only stressed plants germinated in an osmotic stress of '–12' bars, while no germination was observed in unadapted non-stressed seeds. Adaptive mechanisms of drought stress were different relating to stress situation. They were specific escape mechanisms such as avoidance and tolerance mechanisms. Maximum assimilation capacity of a genotype per unit of water lost was more important than characters that ensured survival.

Adaptive strategies for higher productivity under rainfed conditions could be high water harvesting and its utilization–efficiency, developmental plasticity under stress, survival plasticity under stress and high crop growth rates (CGR) on stress alleviation, which might occur either during early stages of growth or during panicle development and anthesis.

Transpiration Quotient (TQ) and water–use–efficiency

The transpiration quotient is the term used to relate productivity to water consumption by transpiration (Kozlowski, 1979) or evapo–transpiration (Begg and Turner, 1776). This was based on the assumption that water use–efficiency, i.e., the ratio of assimilation to transpiration, was a reasonable predictable function of the plant cover and the environment. C_4 category of species were found to be superior in respect of water use–efficiency to C_3 type of species (Ludlow, 1976).

Differences in transpiration quotient and water use-efficiency and physiological characters, which influence these differences, investigated consecutively for two years revealed that little millet (*Panicum miliare*) had the highest water use–efficiency during both the years, closely followed by finger millet (Shasidhar, 1983). In both the species, which differ in WUE, two physiological characters considered important: (1) The net assimilation ratio(NAR) and (2) the diurnal variation in stomatal conductances.

Diurnal variations in stomatal conductances had the other important characters contributing to the differences in WUE ans TQ. Conductances were lower in finger millet during midday resulting in conservation of moisture than in *Paspalum,* which had higher mid-day conductance leading to greater water loss. There were no differences in the threshold water potential for stomatal closure under moisture stress among the species differing in WUE (Shashidhar, 1983).

Maximising biomass productivity with minimum water

Shashidhar (1983) gave detailed account of this matter. Little millets are generally grown under rainfed condition. Moisture stress, which had been often intermittent and unpredictable, was a major constraint for yields. Identification and analysis of growth characteristics and plant types suited to rainfed conditions become imperative. Thus this problem was studied for five consecutive years. Canopy conductance was a function of stomatal conductance per unit leaf area and the leaf area index. Canopy conductances were influenced predominantly by differences in stomatal frequency. Several genotypes were identified, which combined small leaf area and/or stomatal numbers per plant with productivity under rainfed condition equal to or significantly more than the genotypes with large stomatal numbers.

Effect of Salinity on crop yields

Salinity tolerance of a crop depends upon the physiological, genetic, edaphic, climatalogical and pathological factors. Salinity is known to upset the physiological and metabolic activities of the plant. From the reviews made by Asana and Sarin (1966), it was concluded that increasing levels of salt decreased the plant growth, size of the leaf, height of the plant, spikelet number, moisture content of the plant and synthesis of protein, carbohydrate and respiration.

The salt tolerance depends upon the (1) osmotic potential of the tissue sap to compensate for the increase in osmotic potential of the growth medium; (2) the capacity of the plants to regulate the intake and still avoid an excessive accumalation of ions and (3) the inherent capacity of the plant protoplasm to resist the deleterious effects of the accumalated ions (Hayward and Wadlengh (1949).

Studies on the germination of 4 varieties of ragi under different osmatic concentrations revealed that variety *Purna* showed the maximum tolerance to salt concentrations, followed by the variety *Aruna* (Balakrishana Rao *et al.,* 1971). An osmatic concentration of 6 atm. seemed to be critical for the germination of ragi seeds in the presence of Na_2CO_3 and $NAHCO_3$. Germination and early vigour of the ragi varieties were very much affected by the salinity. Germination was satisfactory upto a salt concentration of 4000 ppm. The delay in panicle emergence and decrease in the grain setting with increase in the levels of salinity were observed.

Nineteen genotypes were evaluated for their response to salt tolerance under laboratory conditions. Significant differences were observed amongst the genotypes at different stress levels. All the 5 traits like germination, root length, shoot length, seedling length and vigour index declined with increase in salt stress in all the genotypes. However, varieties CO.12, GPU.28 and Indaf.5 were highly tolerant, while CO.11 was highly susceptible (Shailaja and Thirumeni,2007).

Krishna Sasthry *et al.* (1969) used germination capacity and seedling growth in NaCl and Manitol solutions of different concentrations as a criterion for assessing tolerance. The process of pre-sowing seed hardening increased tolerance to NaCl and high osmatic stress created by Mannitol. However, Kinetin treatment promoted germination under osmatic stress.

Pre-sowing hardening of seeds with $CaCl_2$, Ascorbic acid and BA promoted the germination and seedling growth in high ESP(exchangeable sodium percent). Variety *Purna* did well under high saline condition (Viswanath *et al*.,1977). Shoot growth was also found to be affected by the osmatic stress caused by NaCl and Mannitol. But the pre-hardened seeds were not much affected by the osmatic stress. Osmatic stress due to increase in ESP was shown to affect the ear number and ear weight, which ultimately reduced the grain weight. However, high ESP had less effect on tiller production of pre-hardened seeds. But the ear weight and the ear number of the plants obtained from the control seeds were very much affected as compared to those from the pre hardened seeds. It was also found that seed hardening combined with treatments with growth regulators like BA and Kinetin had given better yields under saline conditions.

Pre–soaking of seeds in water helped in increasing germination capacity under salinity (Bardwaj,1969). Pre-soaking in 0.1% NaCl increased germination of gram and wheat. In saline soils $CaCl_2$ was better than $CaNO_3$ and NaCl Darra *et al*. (1970) observed that effect of salinity on germination could be reduced by pre-sowing soaking of seeds in low concentrations of growth regulators. Sarin (1962) had shown that germination capacity of wheat seeds by pre-soaking with 5 ppm IAA increased the shoot dry weight by 50% and grain yield by 31% when grown in soils with 0.15% salt of Na_2SO_4. Perhaps, this anology might hold good for ragi too.

Effect of salt stress on water relationships and photosynthesis on two varieties under increasing salinity levels (0,1.0, 4.0, 8.0 and 12.0 mmho/cm) was studied by Onkware (1990). Salt stress decreased the leaf water potential, transpiration, photosynthesis and leaf chlorophyll content and increased the diffusive resistance to water vapour transfer to leaves. Variety *Enakuru* suffered more to these adverse effects than the variety *Ekalakala-1*.

Seeds of two varieties *Enakuru* and *Ekalakala-1* were germinated in the presence of 0.0, 0.4, 0.8 or 1.2 s/m NaCl and grown in pots with non-saline loamy soils and irrigated with water having the same concentration of salts. It was observed that 1000 grain weight at 0.1S/m was 3.6 gm for *Enakuru* and 2.6 gm for *Ekalakala-1*. But it decreased with increase in salinity to 1.7 and 1.6 gm, respectively, at 1.2 S/m. Seeds germinated after 48 hours of soaking increased with time. Variety *Ekalakala-1* had higher percentage of germination than *Enakuru* even though both had decreased germination with increasing salinity. Alpha-amylase activity was highest at 48 hours treatment with 0.0, and 0.4 concentration. Amylase activity was similar both at 48 hours and 72 hours treatment at the concentration of 1.2 S/m, whereas, it was the highest at 96 hours of soaking. However, plant height, leaf area and dry weight of seedings decreased at salinity levels of 0.8 and 1.2S/m (Onkware and Ochieng, 1993).

Influence of salt stress on accumulation and partitioning of Na, K, Ca and protein was also studied. Varieties *Enakuru* and *Ekalakala-1* were given saline water of 0.1, 0.4, 0.8 and 1.2 S/m concentration in pot–culture experiments with non-saline soils and observed that increased salinity had increased the Na concentration in young, mature and old leaves and stems in both the varieties although *Enakuru* accumulated more than *Ekalakala-1*.K concentration in tissues differed significantly in *Enakuru,* where the young and mature leaves had higher concentrations than stems or old leaves. However, this was not observed in *Ekalakala-1* even though it had higher shoot concentration of K than *Enakuru.* There was a slight decrease in the concentration of Ca in response to salinity in both cultivars; there were no differences in protein concentration between cultivars although the tissue concentrations were significantly different. Protein concentrations were significantly higher in young leaves than in other tissues.

Variation in response of minor millets, *Pennisetum, americanum,* pearl millet, *Eleusine coracana* and *Ergrostistef* to salinity in early seedling growth was studied by Kebebew and McNeilly in 1995. Seeds of 65 Ethiopian land races accessions, (25 pearl millet, 25 finger millet and 15 of tef), were sown on rafts of black alkathene beads floating on nutrient solution containing various concentrations of NaCl. After 14 days, seedlings were evaluated for the length of the longest root. Although increasing NaCl concentration significantly reduced seedling root length, there was variation within and between accessions within each species. Analysis based on a non-linear least square inversion method using root length data, revealed significant differences in the accessions of pearl millet and tef on the basis of the estimated saline threshold; the NaCl concentration at which root length begins to decrease, did not differ significantly between finger millet accessions. Estimates of C50 and CO, minimum concentration causing 50% decrease in root length and zero shoot growth, respectively, revealed differences between and within accessions for all the three species. Overall, finger millet was more tolerant than tef, which in turn was more tolerant than pearl millet There was a clear evidence that

differences in tolerance were genetically based from broad sense heritability estimates.

Abscisic is acid and responsive protein-indueed salinity tolerance in finger millet was observed by Uma *et al*.(1993) in finger millet. Pre-treatment of seedlings with 200 mM NaCl and the subsequent recovery growth after withdrawal of stress was evaluated when pre-treatment included 10 micro M ABA with 200 mM NaCl, seedlings could survive lethal stress of 500 and 600 mM and recover after the withdrawal of stress. Pretreatment with ABA and NaCl resulted in the appearance of several new proteins of 18,23,31,45,48,54,66 and 68 kDa. The ABA responsive proteins were heat-stable and their accumulation increased with ABA concentration in the medium. This increase was also associated with enhanced tolerance to lethal salinity. ABA alone did not cause synthesis of ABA-responsive proteins or in imparting tolerance to salinity stress. 35-S methionine incorporation studies indicated the synthesis of 21,26,39,45,68,70 and 74 kDa proteins of which 21 kDa was the prominent polypeptide synthesized during induction.

Responsiveness of an ABA responsive 21 kDa protein under stress in finger millet and its relevance in stress tolerance was investigated by Arathi *et al,* (2003). Stress responsive genes expressed in response to mild non-lethal induction stress. Seedlings induced with 200 mM NaCl showed substantially high recovery growth compared to non-induced seedlings. The addition of ABA during induction significantly increased recovery growth when challenged with a very high concentration of NaCl (upto 600 mM). A number of stress responsive proteins were expressed upon induction. Among them 21 kDa protein was the most prominent. 35 S methionine incorporation studies showed that >60% of the total available in the heat stable protein fraction was seen within 2 hours of induction stress. Further the 21 kDa protein was induced under desication (35%RH), low temperature, ABA and together with NaCl indicating that it was an ABA responsive. This protein showed consisderable accumaltion in the mature seed and exhibited a strong cross-reaction with the antibodies raised against the conserved sequence of LEA-1 group of proteins, suggesting that the 21 kDa protein belonged to LEA-1. The relevance of this protein was examined in species varying in stress tolerance. Cucumber, a salinity sensitive species did not show any detectable level of expression of this protein. The relatively tolerant species such as finger millet and *Proso* millet showed higher levels of expression compared to *Setaria,* which was a resistant species, thus signifying the relevance of the 21 kDa protein in stress tolerance.

Phytoremediation of soil contamination

The problem of phytoremediation of soils contaminated with (herbicide) by finger millet was studied by Carmo *et al*. (2008). It was found that prior cultivation of *Eleusine coracana* for 60 days provided a satisfactory initial growth of soybean and tomato cultivated in soils that had previously received the application of Picloram herbicide upto 160g/ha. Thus soybean and tomato form bio-indicators.

Genotypic variability in differential expression of lea2 and lea3 genes and proteins in response to salinity stress in finger millet and rice seedlings

A novel ELISA approach was used to quantify LEA2 and LEA3 proteins and shown the existence of genetic variability in the proteins in finger millet (Jayaprakash et al., 1998). There was a correlation between LEA protein content and stress response to salinity, partial dehydation and absisic acid. Expression of rab 16A and M3, which code for LEA.2 proteins was higher in tolerant than in susceptible genotypes.

Rao and Veeresh (1988) observed that Carbendazim which was a fungicide on blast disease (*Magnaportha grisea*) in ragi also enhanced yields of grain and fodder in the absence of blast disease, when it was sprayed on the crop.

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GENETICS

A clear knowledge of genetics of yield and its associated characters and their mode of inheritance has been of paramount importance as it leads to evolve and execute proper breeding strategies so as to upgrade the qualitative and quantitative status of the crop. Though ragi has been one of the most ancient crops, serving the food and nutritional needs of most of the indigent people living in tropical and sub-tropical areas of the world, very little attention has been paid to study the research needs of the crop. Nevertheless, Coleman (1920) and Ayyangar *et al*. (1931) made an intial attempt. While the former was concerned with the study of natural populations to upgrade their yield potentials, the latter was engaged in genetic analysis of some qualitative characters.

Colour of the earheads in finger millet or ragi was generally green. But some times, it could also be purple pigmented. Purple-pigment was found to be dominant over green and the gene symbols assigned were PP and pp, respectively (Ayyangar *et al*. 1933). However, purple pigmentation was found to be a complex character and, depending upon the intensity of colour, it was divided in to three shades such as purple, dilute-purple and localized-purple. Subsequently, it was observed that two more genes, I and I_2, were also involved in determining the character. In that, it was observed that, if 'P' was associated with both I_1 and I_2, the resultant colour was dilute purple. Paradoxically, two more genes, H_1 and H_2, were also linked with the expression of purple character; but their exact role was, however, not defined.

Rachis is something like a stem in the spike, on which were arranged spikelets and florets. Length of the earhead was determined by the length of the rachis and that it was found to be controlled by two dominant genes, E_1 and E_2. In the absence of either of these two (E_1 or E_2), the length of the rachis was shorter.

There is a good amount of variation in finger shape in ragi. It is generally an open type. However, the presence of the factor Q changed the shape of the earhead into curved or incurved or fist-like,

Vijayaraghavan and Warrier (1949) observed that the genes E_1 and E_2, which were responsible for the length of the earhead (rachis), also simultaneously govern the height of the plant, length of the peduncle and length of the flag leaf. Although, the mode of action of the genes E_1 and E_2, was not explained, a set of genes influencing more than one character simutaneausly, as in this case, it could, perhaps, be a case of **"Pleotropy"**.

Grain colour is yet another complex character. It is generally brown or purple. But there are varieties with white grain types too, which were attributed to the presence of two genes, B_1 and B_2. Either of them singly or together intensified the colour. If they were associated with an additional gene S, then the colour of grain becomes purple. More surprisingly, it was reported by Ayyangar *et al*. (1931), that in an otherwise purple pigmented plants, if gene S was absent the grain colour was white.

Glumes in the earhead cover the grains. They are either long to cover the whole grain or shorter, in which case, they cover the grain partially. Indian varieties have generally been short glumed. Three genes were reported to be involved in the expression of this character (Ayyangar *et al*., 1931).

Chlorophyll is a vital feature of all angiosperms, because it is necessary for the conductance of photosysnthesis, which is an important function of the plant. It is generally green in color, which is governed by two duplicate genes, C_1 and C_2. The absence of these genes resulted in chlorosis. Chlorosis ultimately led the plants to death (Ayyangar and Rao (1931).

Occasionally, some plants were found to have no seed set at all at the population level. It was usually attributed to the phenomenon of seed sterility. Form the closer examination, it was found to be the cause of non-availability of free pollen for pollination and fertilization. This was attributed to the uncharacteristic phenomenon of **agglutination** (clumping of pollen grains). Normal dehiscence of the anther was controlled by gene X. While the dispersal of the pollen was the responsibility of the gene Y. Both of them functioned like dominant duplicate factors and that their presence together should become necessary for normal dehiscence and subsequent release of pollen for free dispersal. Absence or defective functioning of these genes resulted in agglutination (clumping of pollen) leading to seed sterility (Ayyangar and Krishnaswamy, 1931).

Alternatively, seed sterility, was also attributed to possible chromosomal aberrations such as deficiency and duplication, inversions and translocations and other related phenomena. It could also result from the distrurbances in the cell physiology, defective functioning of the genes, insect and disease-damaged sexual parts, abnormal climatic factors and so on (Divakaran and Rao, 1952).

Shanthakumar and Gowda (1997) reported the segregation of grain colour in the F_2 progeny of a cross between WR.9 (green plants with white grain) and U.6 (purple plants with white grain). The purple colour was dominant over green colour and was controlled by two dominant duplicate genes. Progenies of F_2 and F_3 generations segregated into 15 purple and one green. This confirmed the duplicate pattern of genetic control of the grain colour. Similar results were also obtained when the seed colour was brown, in which the F_2 population segregated in the ratio of 15 brown and one white (Shanthakumar and Gowda, 1998). It was suspected that there could have been a linkage between pigmentaion and grain colour. But the study of F_1 and F_3 segregants showed that both the characters were independently controlled by two pairs of duplicate dominant genes.

Prasad and Sudarshan (1983) summed up the pattern of inheritance of some of the characters like plant pigmentation, panicle and grain colour, panicle shape, abnormal spike, glume length, seed sterility, albinism and polyembryoni were governed by 13 independent factors such as B_1, B_2, C_1, C_2, Cx, D, E, I_1, I_2, Q, S, X, and Y.

Ravikumar and Seetharam (1990) in their studies on pigmentaion in the segregating populations of hybrids between pigmented GE.156 and GE.1490 (male) and non-pigmented green GE.301 and GE.442 (female) found in the F_1 progeny the dominance of purple anthocyanin pigmentation. But from the study of F_3 populations, it was found monogenic type of segregation of pigmentation. It was also established that the pleotropic effect of pigmented gene both in the leaf junction at the seedling stage and during flowering stage of the plants in F_1 and F_2 generations.

Investigations on the genetics of male sterility at ICRISAT, Hyderabad (India) in a cross between genetic male sterility line INFM. 95001 and sister male fertile line IE.3318 and three unrelated male fertile lines, FMV.1, FMV.2 and SDFM.957 revealed that F_1 plants of all the 4 crosses were male fertile. But the pattern of segregation in the subsequent generations indicated that male sterility was controlled by one major recessive factor and the gene symbol assigned was ms_1 ms_1 in INFM. 95001, which was used as a female line (Gupta, 1997).

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MUTATIONS

Mutations are defined as sudden changes occurring in otherwise stable plants, at the population levels spontaneously, affecting certain part or parts of the plant. They are either micro (small variations) or macro (affecting many plant parts). They are induced artificially through the use of physical and chemical mutagens. Many a time, micro mutants become useful in correcting the defective plant parts, especially in qualitative characters in commercial varieties of crop plants. They are also useful in unrevealing the nature of developmental variations. Value of mutations in agriculture are indeed immense.

For example, cultivated polyploidy wheats, which have acquired significance in the global food grain basket, owe their origin to a mutation at a loeus on the long arm of the chromosome 5B, which regulates only bivalent paising meiosis and stabilize the genotype (Riley and Chapman, 1958; Riley and Kempanna, 1963).

Kimber (1961) demonstrated a similar event having occurred in tetraploid cottons, which have revolutionized textile industry and its economy in the world today and even cultivated finger millet or ragi (*Eleusine coracana*) is said to be a product of mutation for bolder grain in the African highland race of *Eleusine coracana* ssp. *africana* (Hilu and de Wet, 1976), which has become a significant staple food crop in the arid and semi-arid tropics of Africa and Asia. There are several such instances, which vouchsafe for the stall or role played by mutations in agriculture.

Mutation breeding in ragi was initiated by Krishnaswamy and Iyyangar (1942) through the use of iomizing radiations from their work on the effect of X-rays, they concluded that plant characters like earhead shape and chlopophyu factors mutate easily compared to other characters. Bhat *et al*. (1961) studied the sensitivity of ragi to ionising radiations and reported that LD50 for seedling lethality was 20 KR for x-rays and 30 KR for Gamma rays and lebi than 5×10^{12} pn / cm^2

for pile neutrons. Goud *et al*. (1969) exposed three varieties; *Annapurna, Purna* and H_{22} to Gamma rays at 20 and 30 KR and observed that 30 KR was lethal to seedling growth. They also reported that there were varietal variations in their sensitivity. Variety *Purna* was least sensitive, while *Annapuran* was intermediate.

Kumar *et al*. (1969) also found genotypic differences in response to irradiation. He LD50 data showed that variety *Purna* tolerated as high a dose as 89 KR, whereas the variety *Cauvery* could not stand beyond 44 KR. On the other hand Sreekantaradhya (1971) studied the effect of Gamma rays and EMS, respectively, at 10 to 50 KR and 0.5 to 2.0 per cent concentrations. LD50 for seedling height and fertility was found at 50 DR and 30 KR, respectively. However, the most efficient Gamma ray treatment was observed at 20 KR and the same with EMS concentration at 1.5% in inducing viable mutations although the former had an edge over the latter.

A more elaborate comparative study of the different doses of Gamme rays and four chemicals, EMS, MMS, NMU and MNNG on the variety E. 4840 revealed that the germination and seedling height were greatly hampered under gamma ray treatments increased number of productive tillers were the oherchanges. The speetsum of viable mutations in Mz for ear characters was wider in varieties like HR. 911 and TNAU.294, but narrower in PR.202. Many mutants of breeding value such as dwarfs, early maturity, high tillering and plants with larger earheads were isolated.

An asynaptic mutant was obtained in the variety CO.1 in the M_1 generation following the treatment with 1.5% aqueous solutions of EMS for 8 hours. The asynaptic mutant had 5-7 lose bivalents at meiabics and 99% pollen sterility. Nevertheless it had set fewer seeds, which when grown, were found to be aneuploids. Out of 9 such aneyploids obtained in sub-sequent generation, two were trisomics and 5 were tetrasomies. Pollen sterility ranged between 11.3 to 38.3%. otherwise aneuploid plants looked normal in appearance. At meiosis, extra chromosomes, either remained univalents or paised with their

homologues in the complement to form multivalent. The progeny of such plants comprised disomics, trisomics and also plants with higher chromosome numbers. Nevertheless, asynaptic mutants in finger millet opened up new apportunities to develop chromosome mapping, gene locations and transfer of chromosome (Seetharma *et al*., 1975).

Goud *et al*. (1969) observed chromosomal abnormabilies at meiosis like multivalent, lagging chtomosomes and sticky chromosomes in M_1 generation plants with gamma ray treatment. Seetharam *et al.* (1974) found interchange heterozygotes in M_2 generation of the variety Co.1 following treatment with Gamma ray Gowda and Seetharam (1996), while investigating via-a-vis chemical mutogens (Mahishi, 1975). The seedling survival was very much affected by Gamma rays where as with chemical mutagens, the survival late was inversely proportional. Flowering in M1 generation was generally delayed under most of the treatments and pattern and seed fertility too suffered. Further, morphological abnormalities such gappy ears, apical sterility, partial and highly, sterile plants and peduncle abnormalities were more in gamma ray treatment. Lower doses of both the mutagens were better than the higher does in respect of their mutagenic effectiveness and efficiency.

Byregowda *et al*. (1990) observed that pollen and seed fertility suffered heavily at higher doses of Gamma rays. The other changes noticed in the M1 generation were the number of tillers increased and flowering in general was delayed. The frequency of chlorophyll mutants and viable mutationas fullowed a linear relationship with dosage. There were different kinds of chlorophyll mutants such as chloris, xantha, striata, tigrina and albuia. The xantha and striata were viable with more or less normal fertility. Promising mutant lines selected in the M2 generation in the variety TNAU-294 were superior to the parent variety.

The results of gamma ray irradiation of 4 varieties from 10 to 40 KR revealed that, though there was no significant effect on germination in M1 generation, there was marked reduction in seedling growth, pollen and seed fertility and plant height at harvest. Delayed flowering and genotypic control of response to two levels of gamma irradiation, reported that there was a direct correlation between the degree of response and the radiation intensity as measured through seedling growth and seed and pollen sterility.

Micro mutants affecting quantitative characters like plant height, finger number, finger length and finger breadth were identified by Sreekantarandhya (1971). However, enlarged variance was observed (Goud *et al*. 1971) while the mean was slightly altered with mutagene treatment. Agronomically desirable mutants were identified such as dwarfs, early maturing and cockscomb types in MH_2 generation of the variety HES. 927 (now IE. 927) following Gamma irradiation.

Shivashankar *et al*. (1973-74) isolated an early maturing high yielding and blast resistant mutant with gamma ray treatment. Mahishi (1975) found two open earhead mutants of bractical importance following EMS treatment of variety EC. 4840.

Haider *et al*. (1996) found linear reverse relationship in germination percentage of two varieties of ragi; viz., A.404 and 374, between different doses of Gamma radiation. Similar effect was noted in respect of seedling survival and pollen fertility. Variety A.404 was more sensitive to radiation treatments at all doses than HR.374 panicle length, which ranged from 6.20 to 7.30 cm in A.404 and 6.95 to 7.95 cm in HR 374, increased with Gamma irradiation in A.404 with 30 KR. But in HR-374, it was greater than that in control at 50 KR. However, there was a decrease in panicle length following EMS and combination treatments. Number of fingers per panicle was increased by Gamma radiation in both the varieties. But in EMS and combined treatments, increase in number of fingers was found only in few treatments. Further, Haider *et al.* (1996) found 4 morphological mutants of agronomic value in M_2 generation in varieties A.404 and HR.374 after treatment with Gamma radiation and EMS. Of the grassy mutants obtained, only 3 of A.404 were able to flower. A tall mutant of A.404 was observed in 40 KR and 30 KR+0.2% EMS treatments, respectively and early flowering mutant in HR-374 with 10 KR Gamma treatment.

A significant reduction in germination was observed in 6 varieties after treatment of grains with mutagens. Greatest reduction occurred with Methyl Methane Sulfate (MMS), followed by Ethyl Methane Sulfate (EMS), Gamma rays and Diethyl Sulfate (DES). Variety PR.202 was most resistant to Gamma rays and EMS. However, IE.744 followed by GN.1 and PR.202 were most resistant to MMS, and CO.10 followed by GN.1 and PR.202 were more resistant to DES.

Eight white ragi micro-mutants were evaluated at 4 fertility levels Patnaik *et al*. (1996). Numerical taxonomic method using similarity coefficient was effective in classifying the micro-mutant strains into 4 or 5 different clusters. However, fertility levels influenced the clustering pattern of the strains. Strains Mut. 16-2-1, Mut. 16-4-1 and Mut,18 maintained their individuality by not being grouped with other strains at most fertility levels, indicating that they were the most diverse strains. On the basis of average yield of strains and clustering pattern, it can be inferred that hybridization of Mut. 16-4-2 or Mut. 18-1-2 with Mut-18-4-2 would produce transgressive segregants with high yield.

Useful variants were induced in the variety 852 by Gamma ray irradiation at 5,7,12 and 15 KR. (Mehta and Dhagat, 1994). M_1 and M_2 generations were compared for 6 yield components. In the M_1 generation, survival decreased with increasing doses; but in M_2, survival rate recovered except with 15 KR level. There was a large amount of variability in plant height, number of tillers and number of ears per plant. In the M_2 generation, the mean value of all the traits improved as it was likely that cells with abnormalities were eliminated. The frequency of chlorophyll mutants increased with increase in radiation dosage.

Genetic control and factors involved in the expression of chlorophyll mutants, xantha, striata, tigrina and albina were investigated by Gowda and Seetharam (1996) by studying the heterozygous families segregating for mutant character in the M_2 and M_1 generations, xantha, striata and tigrina segregated in the ratio of 3 normal and 1 chlorophyll mutant. This suggested a monogenic inheritance. Albina segregated in a 57:7 ratio suggesting the involvement of 3 genes one independent and two complementary.

Two varieties, VR.708 and GPU 26 were treated with three doses of each of Gamma rays (150,300 and 450 Gy), Ethyl Methane Sulfonate (0.15, 0.30 and 0.45%) and Nitroso guanadine (0.015, 0.030 and 0.045%) and combined with treatments of 300 Gy Gamma rays with 0.30% EMS or 0.03% NG. Fifteen selected M_2 plant progenies from each of the eleven mutagenic treatments along with the parental variety were evaluated in M_3 generation (Muduli and Misra, 2007). In M_3 generation, out of 165 progenies, 61 in VR 708 and 65 in GPU.26 produced significantly higher yields than the parent and the EMS treatment produced more of such high yielding progenies. In M_4, out of 44 progenies in each of VR.708 and GPU.26, 8 and 9 progenies showed superiority over the parental variety in one or more traits, respectively. Higher frequency of positive mutations was observed for 1000, grain weight, finger length and fingers per ear in case of GPU.26. Among the mutagenic treatments, the frequency of high yielding progenies in M_3 and M_4 generations were higher in 0.30% and).45% EMS, 0.030% NG and combination treatment of 300 Gy Gamma rays + 0.30% EMS.

Continuing the same experiment with a slight modification in combination treatments, i.e., Gamma rays 30 KR with EMS 0.30% or NG. 0.030%, it was found that in M_1 generation, percentage of germination and plant growth parameters were adversely affected. The effects were more pronounced in higher doses indicating almost a loner relationship, adverse effects with increase in dosage expressed more pronouncedly by NG treatments. The frequency of chlorophyll, morphological and total macro-mutations increased with increase in dosages. Morphological mutants were more in Gamma ray treatment. In most cases, higher doses of mutagens induced greater variance and it was more with NG and combination treatments. The correlation of M_1 parameters with M_2 macro-mutation frequency and population variance indicated that the mutagenic treatments showing decrease in germination, seedling height, root length plant height, tillers per plant, fingers per ear and yield per plant in M_1 generation were expected to produce more of both macro and micro-mutants in M_2 generation (Mudali *et al*., 2007).

Sensitivity to chemical mutagens got enhanced if the presoaked seeds were subjected to treatments. Further, Maleichydrozidem, which was so far known to cause only chromosomal breaks, its, preferential induction of micromutants and streptomycin, a cytoplasmic mutagen is less known. However, besides Maleichydrozide and streptomycin, EMS was also used to determine the common effective pre-soaked range using M_1 seedling traits (Singh and Sinha, 2010). Since different M_1 parameters, mutagens and their doses showed different peaks of response, a taxonomic approach was adopted using all characters together. Combinations of chemicals, doses and six attributes of M_1 seedlings gave 48 characters for the numerical classification of pre-soaked periods of 0,8,10,12,14,16 and 18 hours as operational taxonomic units (OTUS). Dendrogram from the similar matrix using UPGMA clustering showed two Clusters: 1) Cluster 1 of three OTUS (0,8 and 10 h PS) and 2) Cluster-2 of four OTUS (12-18 h PS). The effective range was 12-18 hours and 0-10 hr was considered as effective for all kinds of mutagens. The effective range would contain the major peak of sensitivity; the ineffective range might show small peak. These inferences were confirmed with streptomycin-induced albinism as an indicator of plastid mutations. Higher doses shifted the peak within the effective range towards longer PS and low dose towards longer PS. Hence taxonometrivs could be useful by adopted in mutagenesis studies for meaningful analysis.

Three types of variants like curved, straight and top-curved earheads were recovered from the *in vitro* regenerated R-1 generation of ragi plants cultured from seed explants of the variety HR.541, (Kalamani and Sakila, 2001). Individual curved spikes had about 7-12 long fingers and 5-35 short fingers. Many small projections with filled grains were also observed in this type of earheads. Straight earhead types had a few long and many short fingers. The top-curved earhead fingers ranged from 5-6 and resembled the conventional heads. The primary and secondary tillers produced curved and straight earheads, respectively. The tertiary tillers had thumb finger earhead types. The curved earheads had more number of fingers coupled with more grains giving scope for yield improvement.

A finger millet strain IE. 3318 (SDF.63) from Zimbabwe was treated with EMS and induced male sterility at ICRISAT Centre, Kano, Nigeria and released in 1996 as INFM 95001 (PI. 595204) by Gupta *et al.* (1997). Male sterility in this line was genetically controlled by a recessive allele ms. This is expected to facilitate the production of hybrid progeny in this crop since conventional hybridization in this crop is more cumbersome due to small florets and poor success of the crossing rate.

A male sterile line INFM.95001 was derived from a Zimbabwien line IE. 3318 (SDFM.63) at ICRISAT, Patancheru, India in 1997 with EMS treatment and selection through 5 generations. It was homozygous for simply inherited recessive *msl* allele and produced fully fertile F_1 progeny when pollinated by a parent homozygous for Msl Msl for male fertility. The male sterile line could be maintained in heterozygous condition (MSl msl). The mean grain yield was 34.10 g/ plant for male fertile plant in the F_1 hybrid progeny and 1.40 g/ plant for male sterile plant. The other attributes of the male sterile plant was that it had narrower fingers (9.2 *vs* 12.6 mm), more nodal tillers (22 *vs* 3/ plant) and smaller anthers (one fifth of normal) than male fertile plants. INFM 95001 is a medium maturing genotype (94 days to 75% panicle emergence), which produced round, white seeds weighing 3.5 mg in male sterile and 3.00 mg in male fertile plants.

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BIOTECHNOLOGY

Biotechnology is a science that provides a tool to unvail even a subtle variation that exists within the plant populations. It also has a tremendous significance in creating variability that could make a profound impact on the improvement of crop plants for yield and quality. But its efficiency is dependent upon the nature of explants and culture media. Callus formation and its subsequent proliferation are the primary requisites for the success of the plant regeneration.

Das and Misra (2010) studied genetic diversity in 15 finger millet genotypes by using 9 RAPD markers. Out of 25 random primers which were highly reproducible had produced 60 loci, of which 51 were polymorphic. Primer OPC 18 amplified highest number of polymorphic bands. The coefficient of similarity in banding pattern among genotypes ranged from 0.42 to 0.89. The genotypes OEB.65 and 4R.374 and BM.107 and SRS.2 showed high genetic similarity of 0.89 and 0.87, respectively, indicating low genetic diversity and also showed similarity in growth traits. DM.7 and AKP.2 showed the lowest genetic similarity of 0.42, indicating that they were quite diverse. Cluster analysis by UPGMA method grouped 15 finger millet genotypes into one major cluster of 8 genotypes, 15 finger millet genotypes into one major cluster of 8 genotypes and five minor clusters. This indicated that genetic diversity did exist among the genotypes at the molecular level.

In order to study the relationship of presence or absence of a polymorphic bands with genotypic adaptation, 15 early finger millet genotypes were classified into '+' group for presence and '-' group for absence of the band OPA-4 ~ 1800 bp, OPC 12 ~ 900 bp, OPD ~ 850 bp, OPN-7 ~ 2600 bp, OPN 15 ~ 2500 bp, OPN 115 ~ 900 bp and OPN ~ 2600 bp. The genotypes were also classified into high yielding (HY) and low yielding (LY) classes and two adaptability classes, i.e, specifically adapted to rich environments and specifically adapted to poor environments and into two stability classes, stable (S) and unstable (U). The results revealed that the presence of OPA4 ~ 1800 bp and absence of OPN15 ~ 900 bp bands might give some indication about specific adaptability of genotypes to poor environments. Absence of OPA4 ~ 1800 bp and presence of OPN-15 ~ 900 bp would indicate adaptability specifically to rich environments. These results might lead to the prediction of the adaptability patterns of genotypes before going for multiplication trials (Das *et al.*, 2009).

Randomly amplified polymorphic DNA (RAPD) was used to evaluate genetic diversity among 12 selected finger millet accessions, representing different geographic origins and pedigree backgrounds (Fakrudin *et al.,* 2004). A genomic survey employing 37 RAPD primers detected 254 unambiguous, repeatable fragments with an average of 6.86 amplified fragments per primer. A total number of fragments (218) representing 85.82% of the total were polymorphic. However individual RAPD primers differed widely in their ability to detect polymorphism. As expected the genetic diversity observed in African land races was higher than that of Indian accessions. This indicated that the wild finger millet accessions contained a large proportion of genetic variation. Further, lack of polymorphism in the highly bred lines strengthens the hypothesis of genetic erosion during breeding.

Because of low levels of variation in finger millet, RFLP and AFLP, expressed-sequence tag (EST), and simple sequence repeat (SSR) markers were used to generate a genetic map of the tetraploid finger millet in inter-sub-specific F_2 population from a across between *E. coracana* spp. *coracana* cv. Okhole-1 and its wild progenitor E. *coracana* ssp *africana* accession MD 20. Duplicated loci were used to identify homoeologous groups. Assignment of linkage groups to the A and B genomes was done by comparing the hybridization pattern of probes in Okhale -1, MD.20 and *Eleusine indica* acc. MD.36. The map spans 721 cM on the A genome and 787 cM on the B genome and cover all 18 finger millet, a first set of 82 SSR markers was developed. The SSRS were identified in small-insert genomic libraries generated using methylation-sensitive restriction enzymes. Thirty one of the SSRS were mapped. Application of the maps and markers in hybridization-breeding programmes would expedite the improvement of finger millet (Dida *et al*., 2007).

EST-SR markers were developed using sequence information from 1740 expressed tags (ESTS) of finger millet. A set of 31 SSR markers were synthesized based on di, tri, tetra and penta- nucleotide repeat sequences. These were used for PCR analysis of 11 elite germplasm lines of finger millet of Indian and African origin (Arya *et al*, 2009). Out of 31 SSR markers, amplification products were obtained for 17 primer pairs. Of these nine were found polymorphic with two alleles per locus. These 17 primerpairs were also tested for amplification in three varieties of pearl millet and 11 could be transferred to pearl millet. This information obtained from EST-SSR markers could be used in finger millet improvement project too.

Morphogenesis and plant regeneration

A wide range of variability was observed (Kamble *et al*., 2005) for the response of finger millet genotypes to callus induction according to the types of explants in the medium and medium concentrations. The callus can be initited from germinated seeds as well as from coleoptile explants in the finger millet on MS and B5 media containing 2,4-D concentrations and supplementing the media with casein hydrolysate. The callus induction depended on the genotype, type of explant used and 2, 4-D concentration in the medium.

The embryogenic potential of finger millet was assessed in three finger millet cultivars, CO.10, PR. 177 and HR.541 by Kalamani and Sakila (2001). MS medium was used for this study. For the callus induction, the media used was MS+2, 4-D (0.5 mg l-1, 1.0 mg l-1) + Kinetin (o.5 mg l-1). Half MS media + 2, 4-D (0.5 mg (.1)+ Kinetin (1mg 1-1)+ coconut water (5%) and sucrose (2%) was used for callus proliferation and MS+ Kinetin (1mg l-1)+ IAA (0.5 mg l-1) for induction of embryogenesis. Root and shoot induction was done by transfering the embryoids to MS+ NAA (0.1 mg l-1, 0.2 mg l-1)= Kinetin (1 mg l-1) and MS+ NAA (0.1 mg l-1, 0.2 mg l-1)+ BAP (0.2 mg 1-1) media, respectively. Variety PR 177 recorded higher frequency of root and shoot morphogenesis followed by CO.10 and HR.541.

Embryogenic callus differentiated from seeds cultured on MS medium was maintained on a medium with a lower level of 2, 4-D (0.2 mg /l) and every sub-culture had some pre-existing embryoides in it. The resultant sub-culture (callus) retained its morphogenesis potential for 4 years (Prasanna *et al*., 1990). Following transfer to media with different levels of auxin and cytokinins the callus showed various patterns of growth and morphogenesis. Embryoides were germinated from plants, which were transferred to the field. Shoot buds also differentiated from the whole surface of the embryoid or from the flattened meristemoids.

Direct development of shoots from cultured inflorescence segments occurred on MS medium supplemented with 2, 4-D in combination with zeatin. Inflorescence with well developed spikelets differentiated at low frequency (< 5%) from callus cultures initiated on media supplemented with 2, 4-D in combination with zeatin, coconut water or picloram + Kinetin. Somatic embryogenesis was also induced in callus cultures growing on MS supplemented with picloram+ Kinetin at the end of 4 passages. A sucrose concentration of 3% was found most effective for plantlet differentiation (George and Eapen, 1990). The majority of the regenerated plants were diploids and were shorter with an increased number of tillers compared to control.

Immature inflorescence and caryopsis of two varieties of ragi, CO.9 and CO.13, were cultured in MS medium with different growth regulator combinations to find out suitable explants and culture media for efficient plant regeneration (Vadivoo and Vijayalakshmi, 2007). For callus induction MS+2, 4-D 20 mg/l+ kn /0.25 mg /l; for callus proliferation MS+2, 4-D 0.4 mg/ l+ Kn 0.25 mg/ l; for shoot regeneration MS+ 2, 4-D 0.1 mg/ l+ kn 0.6 mg/ l; for root induction in differentiating shoots MS+ NA 0.5 mg/ l, were found suitable. Among two explants caryopsis was found to respond more favorably for *in vitro* culture compared to immature inflorescence. Among two varieties, CO.9 was found better responder for both callus induction and regeneration than CO.13.

Cultured caryopsis of *Eleusine coracana* produced callus from shoot apices or mesocotyls depending upon picloram concentration and combination of cytokinins, in MS based medium. On subsequent cultures, numerous somatic embryos differentiated from the callus on MS medium, supplemented with picloram and Kinetin. The embryos germinated into complete plants on medium without phytohormones. When different carbohydrates were tested, basal medium containing glucose and sucrose, produced the highest frequency of germinating embryos. Supplementation of MS basal medium with a variety of amino acids, osmatic agents and growth supplements had an adverse effect on the germination of embryos. Incorporation of antibiotics such as carbenicillin, cefotaxine and streptomycin sulphate enhanced plant differentiation from somatic embryos. Cytogenetical analysis of regenerated plants showed normal diploid chromosome number in their root tips (Eapen and George, 1990).

Germinated seeds (E-1) and coleoptile (E-2) as explants from 20 finger millet cultured were cultivars in the MS or B5 medium supplemented with 1, 2, 3 or 4 mg 2,4-D and 500 mg casein hydrosylate/ liter. Callus initiation in the dark at 25+ or -2 degrees and 70% relative humidity was evaluated (Kamble et al., 2004). Approximately 15 days after callus formation the cultures were transferred to medium containing 2,4-D for further multiplication. The fresh weight of the calli from E1 and E2 was evaluated at 25 and 35 days after inoculation, respectively. Among the cultivars, Vengurla-1 produced the heaviest callus (82.53 mg). Greater callus weight was obtained using E.1 (70.64 mg) than E-2 (53.79 mg). The effect of genotype x explants interaction on callus weight was significant. The greatest callus weight (119.14 mg) was,

however obtained with E-1 from white ragi. Heavier calli were recorded for the MS medium (67.09 mg). The mean callus weight ranged from 36.05 mg (AVTM-4 in B5 medium) to 114.82 mg (white ragi in the MS medium). Callus weight also significantly varied with 2,4-D concentration and its interaction with cultivar, explants and culture medium. The heaviest calli were obtained with white ragi cultured in the medium containing 2 mg 2,4-D / l; Dopoli-1, Vengurla-1, AVTL-6, IVT-20 and IVT-23 E-1 cultured in the medium containing 2 mg 2,4-D/l; AVTE-1 and IVT-1 E2 cultured in the medium 2 mg 2, 4-D/l; Vengurla-1 explants were cultured in the MS medium containing 2 mg 2,4-D/l.

Satish Kumar *et al*. (2001) developed a protocol for high frequency regeneration of finger millet (cv.PR.202, L-216 and GE-4971) *via* formation of a large apical domes from seeds, matured embryos, immature inflorescence and immature embryos. The induction of apical domes occurred on MS medium supplemented by different auxins 2,4-D, 2,4,5-T and para-chlorophenoxyacetic acid (PCPA) and cytokinins (Kinetin and 6- benzylaminopurin, benzyladenine (BAP). The primary domes after 4 weeks of sub-culturing on MS+2,4-D (0.1, 0.2 mg/l) proliferated rapidly and gave rise to secondary and tertiary domes along with green nodular, compact callus. The domes on MS medium containing GA3 (1 mg /l) or NAA 1 mg/l) gave rise to high frequency of shoot bud differentiation. Multi shoot buds arose over the entire surface of the dome, exogenously. Histological observations provide clear evidence that the shoot apices of the mature and immature embryos transformed into enlarged apical domes and the surface of the domes was occupied by highly mersistematic giant domes and shoot buds were observed in the repeatedly sub-cultured calli raised from mature embryos as well as inflorescence. Similar structures were also seen in cultures raised from immature inflorescence of *Eleusine indica*, a putative A genome donor to *Eleusine coracana.*

Varietal variation in response to somatic embryogenesis of explants of 8 genotypes-CO.7, CO.9,CO-13,CO.14,GPU-26,GPU-28,GPU-45 and GPU.48 was studied by Ceasar and Ignesimuthu (2008). The maximum somatic embryonic induction of 98.6% was obtained from explants cultured in MS medium supplemented with 18.0 mu M dichlorophenoxyacetic acid and 2.3 mu M Kinetin. The highest number of shoot induction (26) was found after transfer of embryonic callus to regenerated medium supplemented with 4.5 mu M Thidiazuran and 4.6 mu M Kinetin. Significant differences were observed between genotypes for somatic embryogenesis and plant regeneration. GPU.45 gave the best response while CO.7 the least. The generated plants were successfully rooted and grown to maturity after hardening in the soil.

Effect of $ZnSo_4$ at 0.1 (control), 0.3, 0.4, 0.5 or 0.6 micro M, and $CuSo_4$ at 29.91 (control), 59.82, 89.73 or 179.46 micro M on callus induction and plant regeneration of finger millet *in vitro* were investigated by Kothari *et al*.,2004. Primary callus induction with $ZnSo_4$ resulted in improved shoot formation upon transfer of calluses to normal regeneration medium. $CuSo_4$ increased to five fold the normal concentration in the media for primary seed callus induction and plant regenerated resulted in a fourfold increase in the number of regenerated shoots. For long term callus cultures, two fold the normal KNO_3 concentration (37.6 micro M) or 4-fold the normal Fe-EDTA concentration (0.4 micro M) could replace the requirement for NAA in the regeneration medium while 60 micro M $ZnSo_4$ or 0.5 M $CuSo_4$ was optimum for plant regeneration from callus cultures.

Basal medium constituents and their concentration play an important role in growth and morphogenesis of plant tissues. Effect of different inorganic nutrients ($CaCl_2$, $MnSO_4$, $ZnSO_4$, $CuSO_4$, and $AgNO_3$) on callus induction and plant regeneration was studied by Chajer *et al*., 2008) in kodo (*Paspalum scrobic-culatum*) and finger millet (*Eleusine coracana*). A 5x and 3x increase in regeneration response at enhanced levels of $CuSO_4$ was noted for kodo and finger millets, respectively. Significant improvement in plant regeneration was also observed with the increase in the levels of Co and Mn. Addition of $AgNO_3$ to the basal medium also had a simulatory effect on callus induction and

plant regeneration. Optimization of nutrient level in the basic medium has thus become highly significant in obtaining maximum regeneration response from explants and callus culture.

Practical utility of the plant tissue culture system was demonstrated by Pius *et al*. (1993) by isolating the sodium chloride tolerant cell lines of finger millet from embryogenesis cultures growing on MS medium supplemented with picloram (2 mg/ liter), Kinetin (0.1 mg/ liter) and sodium chloride (1%) at the end of 6 passages. The sodium chloride tolerant cell lines showed better growth in relation to control at all concentrations of sodium chloride tested, with optimum growth at 0.25% NaCl. When the tolerant lines were grown for 3 passages in the absence of NaCl tolerant calli had more Na+ in comparison with control and they regenerated plants in the presence of 1% NaCl, while the control lines failed to differentiate. When screened in a hydroponics system with 1% NaCl, the tolerant plants grew to maturity while the control plants did not.

Somaclonal variability in finger millet could lead to production of new varieties of some significance has been shown by Bayer *et al*. (2009). Three lines selected from *in vitro* culture, when biochemically analysed, showed that a line SE-1 had high protein content, nitrogenic free extractive substances and dry matter content with low cellulose content. Somaclone SE-4 was found with high sugar content with an indication for having potential to produce bioethanol. Somaclone SE-7 demonstrated high green mass and seed yield.

Transgenic line for leaf blast

Latha *et al*. (2005) have established the reproducible protocols for *in vitro* plant regeneration and genetic transformation in finger millet using particle-in low Gene-mediated method. Using the optimized protocol>4000 plantlets were regenerated from the callus of each shoot-tip explant within 75 days. Plasmid construct pPur, containing Uid A gene driven by CaMV 35 S promoter, was used for developing the transformation system. A gene coding for an antifungal protein (PIN) of prawn was chemically synthesized and was cloned into bacterial and plant expression vectors. Embryogenic callii were co-bombarded with the construct containing pin gene (PPin 355 and another construct containing bar gene (pBar 35 S) driven by CaMV 35S promoter. For stable transformation, the co-bombarded callii were cultured on phosphinothricin (PPT)-supplemented medium. In primary transformants, stable integration and expression of pin gene was confirmed by Southern and Northern blot analysis. Fungal bioassays and basta leaf dip test of T_1 transformants disclosed monogenic 3 resistant to one susceptible transgene segregations. Also, bar and pin genes showed co-segregation in three T_1 progenies analysed, implying single site integration of these genes. This study demonstrated the production of pin expressing transgenic finger millet, exhibiting high level of resistance to leaf blast disease.

Nucleotide sequences are described for this 71-nucleotide long tRNA (Gene Bank accession number UO2636) isolated from 647- bp DNA insert from cv. Indaf 5. Showing 100% sequence identity with rice tRNAGly, this gene does not encode the 3^1-CCA terminus seen in mature tRNA. The 2 prominent consensus motifs of the internal shift promoters, the 5-internal control region GGTCTAGTGG and 3-internal control region sequence GTTCGATTC, were analysed. The A-box and B-box consensus sequences were, respectively, TGGC-NNA GTTG and GGTTC GANTCC, where by the A and G in the A-box, and G, T and C in the B- box were conserved at 100% consistent with their implied role in stabilizing the tertiary structure of tRNA and suggestive of a role in gene transcription. An estimated 6 Gly tRNA gene copies were found per haploid genome. Three direct motifs were recognized in the 3-flanking region. A6 –bp region upstream to the coding sequence showed a region with a perfect dyad symmetry (Ujwal *et al*., 1994).

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CROP IMPROVEMENT

Finger millet or ragi (*Eleusine coracana Gaertn*) has been an important food and fodder crop from times immemorial in India and Africa. Although it is grown all over India, its concentration has been more in southern states of India such as Karnataka, Tamil Nadu, Andhrapradesh, Maharashtra and so on. It is predominantly a dry land crop; yet it responds well to irrigation. Since it is not photosensitive; it grows throughout the year. It has widely spread right from the sea level to higher altitudes up in Himalayas. While its food is highly nutritive and sustatining, its straw is a good fodder for livestock. It suffers from minimum insect pest infestation; but often severely damaged by the blast disease caused by *Magnaportha grisea.*

Original home of finger millet is traced to Highlands of Central Africa (Ethiopia) (Hilu and de Wet, 1996), from where it had spread to neighbouring countries in East and North Africa. It is said to have migrated to India some where around 5000(3000 BC) years ago through Egiptian and or Arabian trade routes. Eversince, it has been under cultivation in several states in India.

It is a third important millet crop next only to sorghum and pearl millet. It is a very tasty and nutritively rich food grain. People involved in hard and arduous manual labour preferred its food. In 1992-94, it had been cultivated in the world in 3.08 million hectares with a production of 2.8 million tonnes (FAO Report). According to latest statistics,its annual production was 2.1 million tonnes from an area of 1.63 million hectares. India produced 60% of the global production. The productivity of the crop had gradually increased in the last two decades touching 1.35 tonnes per hectare during 2003-04. It was a happy augury that it had touched 1.80 t / ha. and in some states, it was even better at 3.00 tonnes per hectare. But in Africa, it was as low as 0.60 tonnes per hectare, as per example, in Kenya (Devos, 2005 FAO Report).

Obviously the low yields, which could not compete with those of more progressive cereals like wheat, rice, corn and so on hastened up apathy and neglect towards this crop, which contributed to the rapid decline in its prospects. Ragi being one of the contributor to the global grain resources, there is an urgent need to revive the crop through intensified research, especially breeding researches.

It is easier said than done, unless there are right type of genetic resources available at hand, that could be gainfully harnessed to upgrade the yielding ability and the quality of the crop.

Genetic Resources

A team of Scientists under the leadership of Dr. A. Seetharam, Former Project Coordinator for the Improvement of Small Millets (ICAR) at the University of Agricultural Sciences, Bangalore had organised a detailed analysis of global collections of 5669 accessions during 1996-2005. the study was conducted in India at 4 locations, viz., Almora (up in the Himalayas), Ranchi (North India, Bihar), Vizianagaram and Bangalore (In Deccan Plateau region). The Methodology used was through initial grouping of accessions by using characterization data relating to purple pigmentation in various parts of the plant, grain clolour, grain shape and shape of infloreseence. The data were subjected to cluster analysis using SYSTAT-9 package. Cluster comprising a large number of accessions were further processed into small clusters, which in turn were processed through Principal Component Analysis using SPLUS 2000. Further, using PCA scores around 10% of the accessions were selected for making a ***Core Set***. The means and variance of the entire collection and that of Core Set were compared in respect of important quantitative characters inorder to ensure whether the core set respresented the entire collection for the variabilty present in the germplasm collections.

Based on this data a Core Set of 551 accessions was constituted, which comprised the accessions originating from many countries in Africa, in the Indian sub-continant and from else where:

Sl. No.	Country	No. of acessions
1.	India	379
2.	Ethiopia	2
3.	Kenya	48
4.	Malawi	55
5.	Tanzania	4
6.	Uganda	24
7.	Zambia	12
8.	Zimbabway	7
9.	Sri Lanka	3
10.	Japan	3
11.	Others	14

Source: Finger Millet (Eleusine coracane) **Core** Germplasm Utilization in Crop Improvement by Seetharam *et al.,* (2005).

Experimental details, Characterization, Discriptors, Evaluation and Grouping of Core Germplasm and their frequencies have been clearly deliniated in this document.

The ***Core Set*** represented the collections from both the geographical regions such as Africa (Primary Centre of Diversity) and Indian sub-continent (Secondary Centre of Diversity). The pattern of variability of the entire Core Collection *vis a vis* that existed between the two Core Sets from two regions was summarised and documented in the book: "Finger Millet (*Eleusine coracana* L. (Gartn), Core Germplasm for Utilization in Crop Improvement" and published by the Project Coordination Cell (All India Coordinated Small Millet Improvement Project, located at the University of Agricultural Sciences, Bangalore, India).

Comparison of the data in respect of various quantitative characters between two regions revealed the existance of substantial quantity of variability for all the characters studied. The vital segment of the Core Set was the presence of genetic diversity for a charactor or a group of characters, which would be useful for utilization in crop improvement. The ***Core Set*** of 551 accessions have been reposited at the National Active Germplasm Site at AICSMIP, Bangalore. The Core Set for yield and yield attributes including the values for protein and calcium contents was further confirmed by Jayaramegowda *et al.* (2008).

Upadhyay *et al*. (2006) also developed a Core Set of 622 accessions based on the data on 14 quantitative characters from a total of 5940 accessions held at the gene bank in ICRISAT, Hyderabad. The comparison of variance, frequency, distribution, Shannon Weaver diversity index (H^1) and phenotypic correlations indicated the core sub-set represented the entire collection. The tests also indicated that sampling was optimal and diversity had been accessed very well in the core sub-set. However, the correlation analysis indicated that lower priority be given for the characters like panicle emergence and the longest ear length in the future evaluation of finger millet accessions.

Melanie Newman (2005) of the Plant Genetic Resource Conservation Unit at Griffin, USA had built up a repository of a Core Collection of 80 accessions, representing the range of genetic diversity of over 700 samples collected from various regions of the world (FAO Report).

Genetic Diversity based on D^2 analysis

Sheriff (1992) studied 20 varieties for 9 metric traits, both under dryland and irrigation, at Bangalore, analysed the data through D^2 test and grouped the material grown under dry conditions into 4 genetic clusters and that under irrigation into 11 clusters. Six traits were common to both, contributing most to the genetic diversity. For example, varieties Indaf.3, Indaf.8, ROH.2 and ROH.7032 were markedly diverse under irrigation.

Reddy *et al*. (1993) studied 50 genotypes from diverse eco-geographical regions for 11 morphological features and subjected the data to D^2 and Canonical analysis. The genotypes differed in respect of almost all characters, clustering pattern of the genotypes indicated that the genetic diversity did not seem to relate to geographical origin. Days to 50% flowering contributed most to total genetic divergence.

Clusters VII, IX and XII were the most divergent and also produced the highest mean value for most of the characters. In another study, 46 genotypes studied for 8 quantitative characters grouped into 5 clusters (Jayal and Haider, 1994). Days to maturity was the highest contributer to the total divergence, followed by ear length, harvest index and number of fingers per ear.

Assessment of genetic diversity in 178 genotypes by Satish *et al.* (2007) revealed that genetic diversity did not relate to geographical origin. All the genotypes were grouped into 10 clusters. The inter-cluster distance indicated that cluster II and cluster V were highly divergent. Number of florets per spike was the major contributor to inter-cluster divergence. Among all the clusters, cluster VII showed high mean across 15 traits, followed by clusters V, VII and IV. It implied that these clusters were resourceful for promising genotypes for breeding.

One hundred and fifty accessions analysed for genetic divergence by Prabhu *et al.* (2008), grouped into 18 clusters, of which 14 clusters, were having solitary accession each and were found to be superior. These clusters were: II, III, V, VI, VIII, X, XI, XII, XIII, XIV, XV, XVI, XVII and XVIII. It was presumed that hybridization between the members of these clusters might yield a broad spectrum of variation, from which superior genotypes could be selected for the improvement of the crop.

From 70 accessions studied for 15 characters by Kadam (2008) at Kollhapur, 8 clusters were identified through D^2 analysis of 15 characters. Cluster I was the largest with 38 genotypes, followed by Clusters II, III and IV with 20, 6 and 2 genotypes, respectively. Higher Cluster distance was observed between cluster VIII and V, followed by Clusters VI and II. Cluster II had the highest mean value for grain yield per plant, 1000 grain weight, finger number and flag leaf width. Cluster VIII contributed to maximum genetic divergence. There was a parallelism between geographical diversity and genetic diversity. It was suggested to cross genotypes from Cluster II and I with Cluster

VII because of the higher cluster distance coupled with higher grain yield to improve the yield of the crop.

Fifty genotypes were analysed for 10 qualitative characters to determine the genetic divergence through D^2 test by Anantharaju and Meenakshiganeshan (2008). Out of a total of 14 clusters identified, Cluster I had 17 genotypes, Cluster V with 6, Cluster VI with 7 genotypes and Cluster II and Clusters IV to VIII consisted of single genotype each. Considering the inter-Cluster distance, it was the highest between Cluster XI and XIII, followed by the Clusters V and XI and XIII and XIV. The genotype, MS 3221 of Cluster IV had the highest mean for grain yield and productive tillers. For number of fingers, genotypes TNAU-972 of Cluster IV and Indaf-II of Cluster III, for finger length, genotype PR.202 of Cluster X and for 1000 grain weight, AF.2060 of Cluster XI was found superior. Among all the characters, days to 50% flowering followed by number of leaves contributed most towards total divergence.

Studies into the pattern of variation in seed protein at Tarai (Garhwal, Uttarkhand) were made by Bandyopadhyay *et al.* (2007) by using SDS-PAGE technique. UPGMA Cluster analysis corroborated the analysis given by SDS-PAGE and showed distinct separation between local and improved cultivars. GPU.45, VL.316 and HR.374 shared close similarity. RAU.8 and PRM.9801 grouped into separate Clusters and maintained genetic distance with other Cultivars of finger millet in the area. Heterogeneity with populations of VL.146 and PR.9803 was, however, observed.

A total of 40 genotypes were studied for genetic divergence through anatomical traits related to blast reistance (Jain *et al.,* 2005) led to the identification of 4 Clusters. Several exotic genotypes such as GE.1370, GE.3022, GE.3024, GE.3058 and E.3060 were found to be resistant to blast disease (*Magnaportha grisea*). Clusters I and III were most divergent, followed by Clusters II and IV. Whereas, Clusters IV and V were least divergent, followed by Clusters II and III. The genotypes of Cluster III exhibitted the least mean incidence of leaf blast (3.97%), neck blast (0.13%) and finger blast (0.55%). The genotypes grouped in Cluster III possessed high degree of resistance against blast. These genotypes also possessed comparatively higher estimates of leaf epidermal thickness, leaf cuticular thickness, neck epidermal thickness and lower number of chlorenchymatous strands in the neck region.

Genetic diversity of 12 lines, which *inter alia* included the line VL. 149 twice from two regions, was studied by Kanchan Kumar and Anita Pande (2010). Three replicas of each accession was amplified by using 17 random primers. A total of 113 distinct fragments ranging from 117 bp to 2621 bp were amplified. Of these, 70 (61.9%) were found to be polymorphic. A finger print for GPU.28 was obtained. Another finger print for genotype VL.135 was generated where two primers (T.10S6 and T.20S4) could distinguish from other genotypes either by absence or by presence of an allele, respectively. In addition, another interesting allele, which was absent in the genotypes of high altitudes (VL.324, VL.315 and VL.149) was isolated. The lowest and the highest polymorphisms were obtained with in individuals belonging to genotypes, OUAT.2 and VL.324. Nei's analysis revealed the highest similarity between OUAT.2 and JWM.1 and the highest between Bm.1 and VL.315. OUAT.2 and JWM.1, both white-seeded cultures, showed maximum closeness. This study helped in identifying the cultures in a quick and reproducible manner and their relatedness.

Pattern of variation

Eleusine coracana Gaertn had originated several millennia ago in Ethiopia (Africa). It had spread to many parts of the world, especially to Asia and Africa. Its agrarian history too has been very long. In view of long evolutionary history and wider distribution, would have exposed it to an array of agro-ecological and socio-economic millieu in order to make it sustainnable in the given environments. Consequently, it must have undergone several modifications in its morpho-genetic and agro-physiological systems. It is, therefore, not uncommon to expect the occurrence of abundance of vatiation in its phenological build up at the population level in consonance with the Vavilovian concept of natural populations having long ancestral history and wider geographical distribution. Thus it is possible to find both external (phenotypic) and internal (genotypic) variations with the natural populations.

Phenotypic variation

The first-ever attempt to make a systematic study of *Eleusine coracana* Gaertn (finger millet/ragi), dated back to 1920 by Dr Lesli C.coleman. But it was a limited study confining to a smaller population, covering the states of Karnataka and Tamil Nadu in South India. Based on just about 3 characters like earhead shape, glume and grain colour, he could identify 7 types. This gave a stimulus to perceive that there could be much more variation if such a study were to be extended to wider areas with in India as well as to north and east African regions where ragi has been under cultivation for near about three millennia, and perhaps, even more.

With this perception, 619 accessions were procured by Kempanna and Tirumalachar(1968) from the National Bureau of Genetic Resources (ICAR), New Delhi (Courtesy; K.O. Rachie of Rockefeller Foundation in India). This collection *inter alia* contained 78 from Africa and the rest from India. They were grown continuously for 3 years, 1966 through 1968 at the University of Agricultural Sciences, Bangalore. It was indeed a revelation that most of the morphological features threw out abundance of variation. Detailed estimates of this variability were made separately for each set from Africa and Asia (Ibid: Chapter Botany). There were some parallelisms and digressions in the matter of certain morphological features between the two sets.

The pattern of variation of the species was studied by Kempanna and Thirumalachar (1968) and Kempanna (1975). Only few characters were chosen for detailed analysis:

Plant Height: it was a most conspicuous character for its variation. It was very vulnerable to environmental fluctuations. There were very tall, tall and a few medium-tall lines were in majority with African material. But none in the dwart eategory. On the other hand, all the 4 categories - very tall, tall, medium - tall and dwarf forms - were found with the Indian accessions. Dwarfs accounted for only 10% of the collections involved in the study.

Maturity Period: Maturity period (duration) is another feature having an important bearing on the crop. Five maturity forms were found with African set. They were very early, early, medium, late and very late categories. Medium duration category predominated and scored as much as 86.66%. By contrast, the Indian collections were characterized by all the 5 forms. But very early and very late forms were few, accounting for 3.72% only.

Glume colour: It is yet another distinguishing feature in the finger millet. A total of 6 shades were found with the African group. They were Purple-madder, Cyprus-green, Shell-pink, Claret-brown, mixture of Claret-brown and Cyprus-green and mixture of Purple-madder and Cyprus-green. By contrast, Purple-madder and Cyprus-green were the most predominant, scoring 98.40% with the Indian group. The remaining 2.60% was represented by Shell-pink category.

Matured grain color: Only two shades – Brick-red and Orient-pink – could be noticed with the African material. Whereas, Indian material had thrown out a basket of shades: Brick-red, Coral-pink, Shell-pink, Orient-pink, Purple-madder, French-rose and Peach colour. However, Brick-red and Orient-pink shades were common. Interestingly, the very same shades were dominant with the African set too. But Brick-red shade in both the groups was sub-divided into 4 shades depending upon the intensity of the colour. Nevertheless, Brick-red colour of the grain was the major grain colour in both the groups.

Earhead character: This character showed maximum variation. African group had 21 different head types as against 13 main types and 20 sub-types with the Indian group. However, Types.12 and 20 of African group were similar to Types 12 and 4 of Indian group, respectively. Similarly, African Type.2 was comparable to Indian Type.8.

This study of germplasm, limited though, as it is, notwithstanding its origin from two distint geographical regions, demonstrated the evidence of more parallelisms to commend than digressions in the matter of broad spectrum of phenotypic variation between the two sets. Nevertheless, further studies on Indian types, only on just two characters, viz, height of the plant and maturity period (duration), an interesting pattern of variation had emerged, which seemed to have a bearing on geographical distribution (Ibid: Chapter on Botany).

It is a known fact that two geographical regions have been seldom alike in the matter of developmental pattern of variation. So the generalized account of variation patterns do not often reflect the true picture, unless they are broken into sub-geographical entities and reappraisal is made (Vavilov, 1951; Kempanna, 1975).

Based on agroclimatic considerations, India has 16 zones, each one having its own unique features, in the matter of characteristic patterns, save some minor overlaps. Ragi has been in cultivation in almost all these regions though not to the same scale.

In consonance with Vavilovian concept, it is possible to find an element of non- randomness in the pattern of height distribution between the zones. Nevertheless, in certain cases, the contiguous regions (states) might have digressed the political boundaries in a particular zone. Based on this premise, three macrozones with a microcentre could be recognised in the matter of distribution of height categories. On the other hand, four major-zones, two sub-zones (less defined pattern though) and one micro-center could be identified with regard to the distribution of maturity categories (duration). Agro- economical and geo-ecological compulsions might have played their role in the development of the apparent zonal heterogeneous patterns (Kempanna, 1975).

Marian Ghiorghis (1993) studied 192 accessions, comprising 119 from Ethiopia, 64 from Zimbabway and the rest from Zambia and were characterized for 17 classes at Melkassa Research Center in Shewa (1550 MSL) in Ethiopia during 1987. Simultaneously, 25 from the same stock were sown at Pawe Research Station in Gojam (1100 meters) in the same season. Variation between accessions was high, but it was the same in respect of 8 traits in localized exotic materials. The presence of Afro-Asian genotypes were observed in the Ethiopian collections. The exotic genotypes were shorter, matured earlier and produced smaller seeds; some seeds were occasionally dark in colour. Plants grown at Pawe were significantly shorter than those at Melkassa. Here, they matured a week later, but showed only small variation in the other characters.

A total of 925 accessions were evaluated for yield and yield attributes at Bangalore by Mallanna and Khalak (1976). A wide specturum of variation was found in respect of maturity period, plant height, grain yield, grian-bearing area in the earhead and grain density. But in respect of tiller number per plant, there was hardly any difference. It was reported that dwarf and early maturing types were found in the accessions from the northern hill region. Whereas, the variation for higher yields were from southern region comprising the states of Karnataka and Tamil Nadu. Characteristically, African collections were poor in tillering and non-uniform in grain size, and highly sensitive to environmental changes. High yield potentials combined with fairly good resistance to blast disease were the other high points of this group.

Mnyenyembe and Gupta (1988) evaluated 196 germplasm accessions from Malawi at Chitedge and Makoka Research stations during 1985 through 1989. Differences in variation between accessions for number of days to flowering, plant height, finger length, finger width, number of fingers, number of productitive tillers, grain yield and finger blast incidence were significantly high at both the locations. Nevertheless, 6 accessions with highest values and six with lowest values for each character were identified.

A total of 364 germplasm accessions from Zimbabway were evaluated at Bangalore in India by Ravikumar *et al. (2000)* to determine the extent of variation present, Differential behaviour was obrerved in

terms of growth and flowering pattern and correlations over two seasons. They exibitted wider variation for different traits. Correlation studies in both the seasons had shown higher values for plant height, earhead length, finger length, finger number, harvest index and total dry matter.

Wider intra - and inter-population variability was observed by Tiwari *et al* .(2004-05) in land races grown at Begnes and Kaski in Nepal for most of the qualitative and quantitative traits like plant height, leaf number, length of flag leaf, finger branching, finger type and size and spikelet shattering. Large sized ears were found at Saka Dalle and Sangkhode. The Cluster analysis brought together land races eco-geographicaly into two distinct groups. They were useful for varietal improvement for wider adaptation.

Amgain *et al.* (2004-05) reported that many geographical niches in Nepal have shown large diversity for finger millet land races. Five land races from midhills (Begnes and Kaski) and two land races from Central Terai were evaluated for 18 qualitative traits. They have shown large intra-population variability. Similarly, 8 quantitative characters were more variable in the Sato Dalle population. This was explained as a sign of natural evolutionary process still being active. The shortest duration of flowering and maturity with high variability were observed at Jhalari.

In another trial, 28 morphological classes for 11 quantitative characters were identified in the population with higher polymorphism in earshape (5 classes), followed by grain colour (4 classes). Spikelet shattering was found in Jalari and Muna. The Kato Jhype population showed non-synchronous ear maturity. Quantitative traits except tiller number, finger length, finger width and grain yield per plant were normally distributed without skewness.

Gain yield per plant was negatively correlated with days to flower and maturity. But it was positively correlated with tiller number, leaf number, blade length of flag leaf and of its width, finger width, grains per spikelet and finger number.

Terai and Hilly land races were grouped into two classes. The inter- and intra-population variation found in the land races could be useful for finger millet improvement. The land races of Terai could serve as the gene pool for earliness and yield for Terai conditions.

A total of 64 accessions of land races, which included five from former region of Ethiopia and Eritria, were evaluated for growth habit, ear shape, grain shape, grain colour and pericarp resistance to establish the phenotypic diversity (Bezaweletew *et al.,* 2006). The percentage frequency of each character was calculated. The Shanon-Weaver diversity index (H^1) was used to estimate the magnitude of diversity for individual characters. One way analysis of variance of non-normalised 'H' using regions was done for individual characters, which showed marked difference in their distribution and variation. No cases of mono-morphic classes was observed. Regionwise, Gojam and Welega revealed the higher diversity (H^1 =0.84), while Eritria showed the lowest (H^1= 0.67). There was an increasing trend of diversity from north to south. Overall characters revealed intermediate to high diversity ranging from 0.60 for pericarp persistence to 0.99 for grain surface. Earshape and grain surface showed different levels of diversity among regions as opposed to growth habit, grain colour and pericarp resistance. The overall mean diversity estimate was high (H^1=0.82). Generally, the results revealed the existence of a vast range of diversity in the indigenous finger millet germplasm.

Genotypic variation

Apparently, considerable amount of variation has been found with most of the morphological features. Consequently, it would be interesting to understand the genetic pattern of variation of yield and its attributes as it becomes an useful adjunct for rational choice of breeding materials for the improvement of the crop.

Yield is a compound character as it is quantitatively inherited and thus offer no scope for simply advancing the cause of breeding. However, Graffius (1964), while analyzing the yields of small grain crops, treated them as rectangular parallelipiped, the edges of which represent the immediate components into which yield could be conveniently partitioned such as spikelets per plant, seeds per spike, seed weight and so on. Thus it emphasises the importance of approaching the genetics of yield through the genetics of its components.

With this premise, 22 cultures, randomly selected from the germplasm collections, which *inter alia* included, the cultures from three distinct divergent regions such as Bihar, up in North India, Karnataka and Tamil Nadu in South during 1966 through 1968 at Bangalore reflected significant intra-regional differences in as much as inter-regional differences did. Genotypic coefficient of variation (GCV) for garin-bearing area and number of tillers per plant was of high magnitude, which was supposed to be responsible for higher GCV in respect of grain yield (Kempanna and Tirumalachar, 1968; Kempanna, 1975).

A total of 1064 accessions were analysed by Bhaskariah and Mallanna (1997) and reported high CV and GCV for several characters like number of tillers, panicle length and straw yield. Several earlier studies on this subject, Chowdhury and Acharya (1969); Bhagat *et al,* (1972) and Rao and Parathasarathy (1968) also noted similar trends. Ramaswamy *et al.* (1994) studying 40 genotypes in respect of 6 yield characters had found that CV and GCV were similar for days to 50% flowering and green fodder yield. But the same differed significantly in respect of number of leaves and leaf weight, which was reflected in the low heritability values for these characters. Maloo *et al.* (1998) observed that 50 genotypes evaluated at Udaipur had given high GCV and high heritability for seed protein, iron and calcium contents. It was also observed that these characters were governed by additive gene effects.

Twenty one varieties grown at 3 locations with widely differing agro-climatic conditions varied in their organic matter content, nitrogen and NDF among locations as well as between themselves. The nitrogen content with 0.6% was the lowest and NDF with 67.8% and *in vitro* digestibility of 37% were the highest in samples from the locations coming under highest rainfall. However, the organic matter digestibility did not vary both between cultivars and/or locations (Rao and Prabhu, 1993).

Abraham *et al.* (1989) tried 20 diverse genotypes at Shillong and found that CV and GCV were high for effective tillers per plant, 1000 grain weight and number of fingers per year. Heritability in the broad sense was high for days to maturity (99.5%), days to 50 % flowering (97.7%), fingers per ear (83.3%) and 1000 grain weight (98.1%). Genetic gain was high for grain yield per plant (56.3%), 1000 grain weight (39.7%) and fingers per ear (33.9%). Grain yield was significantly and positively correlated with days to 50% flowering, days to maturity, effective tillers and 1000 grain weight. It was observed that simultaneous selection for days to flowering, days to maturity and 1000 grain weight might result in the improvement of the crop for better productivity and production.

Six finger millet genotypes were evaluated by Chaturvedi and Srivatsava (2008) for physical properties such as popping quality, sensory quality and nutritive value of popped grains. Genotypes varied for popping characteristics. Amber coloured genotype (PRM.701) was found with higher value for 1000 kernel weight as well as for crude protein content, Ca, Fe and *in vitro* protein digestibility. Prolamine was the major protein fraction and was maximum in amber coloured genotypes. Positive correlation was observed between flake size and globulin content of the grain. Popped grains of all the 6 genotypes were sensorily acceptable.

Genetic variation in yield components in relation to resistance to *Magnoportha grisea* blast in 4 F_2 populations revealed moderate to high genetic variability for yield and *M.grisea* infection. The disease incidence, yield per plant, days to 50% flowering and plant height showed high heritability and genetic advance, which suggested the effect of additive gene action (Ravikumar and Seetharam, 1994). The results indicated that there was scope for isolation of blast resistant (*M.grisea*) types.

Generation mean analysis in finger millet of 8 quantitative characters in 4 F_1, 4 F_2 and F_3 populations involving 6 parameters, showed the importance of both additive and non-additive gene action for all the characters (Marimuthu and Rajagopalan, 1997). Predominance of additive gene action was observed for days to 50% flowering, plant height and 1000 grain weight, while the non-additive gene effects predominated in the inheritance of number of productive tillers per plant, number of fingers per ear, finger length, ear weight per plant and grain yield per plant.

Heritability and Genetic advance

Heritability in the broad sense is expressed as the proportion of genotypic variability to the total observed variability. Predicted genetic advance is an estimate of the product of the ratio of genotypic variation to phenotypic standard deviation. The selection differential (K) provided by Lush (1949) was used by Viswanath and Mallanna (1997) in their studies. They observed high heritability and high genetic advance for plant height, panicle length, straw yield and grain yield in the material they used.

Heritability values vary between environments, crops as well as with different methods of estimating. Thus the heritability estimates were only relative but not absolute. Further, as pointed out by Swarup and Chougule (1962), high heritability need not necessarily mean high genetic advance. So Johnson *et al*. (1955) suggested that heritability should always be considered in conjunction with the genetic advance in order to get a better estimate.

In the analysis of 22 cultures made by Kempanna and Tirumalachar (1968) and Kempanna (1975), the heritability values for days to ear were: 84.12, for plant height: 85.46, for number of tillers: 51.25, for total grain bearing area: 91.18 and grain yield: 61.26. Similarly, the genetic advances for all the characters (in the same order)was 22.39, 39.29, 40.85, 85.96 and 49.45%, respectively.

Goud and Lakshmi (1977) reported high heritability (broad sense) for plant height, number of fingers per head and moderate for tiller number. Shanthappa (1979) analyzing F_2 segregants, using parent-offspring regression, reported high (narrow sense) heritability for grain yield. Shankar (1982), using 6 generation mean method suggested that inheritance of flowering, number of productive tillers, plant height, days to maturity, ear and straw weight could be governed by additive gene effects.

While high heritability was observed for grain yield by Kempanna and Thirumalachar (1968) and Chaudhury and Acharya (1969), moderate heritability was observed by Patnaik (1968) and low heritability by Bhagat *et al.* (1972). Such discrepancies in the heritability estimates for the same character were accounted for by differences in the source of material, environment in which studies were made and their interactive effects, if any (Viswanath and Mallanna, 1997).

Studies conducted by Patnaik *et al.*(2004) on variability, heritability and genetic advance involving 5 promising parental lines and three F_2 crosses revealed that parents were found to be significantly different between themselves with respect to days to flowering, panicle length, finger length, days to maturity and seed weight per panicle at 1% level, while it was at 5% level for finger number per panicle and tillers per plant. The F_2 population of 3 crosses also exhibited high significant differences with each other in respect of days to maturity. Whereas the differences were significant at 5% level for number of fingers per panicle and tiller number per plant. In the parents versus crosses, plant height, panicle length and days to maturity were significantly different at 1% probability level, while fingers per panicle were significant at 5% level. High heritability values were found with both the parents and F_2 generations for days to flowering, panicle length and finger length. In the parents, genetic advance was high for panicle length and days to flowering, which suggested that there is sufficient scope for improvement if selection is based on these parameters. In the F_2 generation, the genetic advance was more than 10% for days to maturity, finger length and panicle length.

Yield is a complex character as it is an aggregate of all the components of yield. Kempanna (1975) reported that heritability estimates and genetic advance in respect of grain-bearing area, grain yield, plant height, number of tillers, number of internodes and days to ear were of high magnitude. However, in three out of six characters, the genetic advance was the highest under kharif-rainfed-environment, which was as high as 153.01%. Incidentally, ragi is mainly cultivated during kharif season under rainfed condition in most parts of India. Heritability values and genetic advance, if considered together as suggested by Johnson *et al.* (1955) and Swarup and Chaugale (1962), the grain yield, total grain-bearing area, number of effective tillers and plant height offer good scope for the improvement of the crop yields, particularly under kharif-rainfed-environment, which is the main crop season in India.

The estimates of genotypic differences showed considerable variation for most of the characters in the population of 178 genotypes (Satish *et al.,* 2007). High heritability in combination with high genetic advance was observed for number of tillers, days to 50% flowering, finger number per ear, length of earhead, length of fingers, number of florets per spikelet, ear weight, test weight, straw yield and grain yield. This indicates that these characters were controlled by additive genes. However plant height, days to maturity and flag leaf length exibitted higher heritability with moderate genetic advance, suggesting the operation of both additive and non-additive gene effects.

Variability, heritability and genetic advance in respect of 11 quantitative characters studied in F_2 population of three crosses (Indaf.5 x GE.1462; PR.202 x GE.1409 and Indaf.9 x GE.1409) during 2002 by Anand *et al.* (2005), the grain yields of sub-tillers, exhibitted highest genotypic and phenotypic coefficient of variation. In general, plant height, yield of sub-tillers, seed density and total grain yield per plant showed high broad sense heritability. Genetic advance was high for grain yield of subtillers in all the three crosses. The grain yield of main ears and sub tillers, seed density and total grain yield showed high heritability coupled with high genetic gain. Cross Indaf.5 x GE.1462 produced the highest number of desirable segregants, followed by Indaf.9 x GE-1409 and PR.202 x GE-1409 (Anand *et al.,* 2005)

A total of 162 recombinant inbred lines obtained from the cross CO.9 x TNAU.946 revealing that high heritability combined with high genetic advance in respect of number of tillers per plant, finger number per ear, finger length, 1000 seed weight and seed yield per plant indicated the presence of additive gene effects. However, some traits such as days to 50% flowering, plant height and straw yield per plant expressed high heritability in conjunction with moderate genetic gain (Ganapathi *et al*., 2007).

Bezeweletew *et al.* (2006) in Ethiopia studied 15 characters in 66 accessions and reported that heritability estimates ranged from 20% for grain filling duration to 80% for days to head. Genetic gain ranged from 6.67 to 44.14% for grain filling duration and finger width, respectively. Finger length and width exhibited high heritability along with high genetic gain. The strongest positive association was between culm thickness and leaf blade width, while the strongest negative association was between 1000 grain weight and finger number. Grain yield per plant was associated positively with productive tillers, 1000 grain weight, number of grains per spikelet and finger number. Whereas it was negatively associated with days to heading and maturity. The genotypic correlation and path-coefficient analysis showed that 1000 grain weight, finger number and productive tillers were the major contributors to grain yield per plant.

Study of F_2 population for variability and inheritance of biochemical compounds determining resistance to blast, yield and other attributes during 1994 by Byregowda *et al*. (1999) showed that genetic variability was large for all the characters, except seed protein content and fingers per ear. Protein content showed moderate heritability with moderate genetic advance reflecting predominance of both additive and non-additive gene effects.

Forty two mutant lines derived from white ragi variety CO.9 grown during rainy season showed moderate to high heritability and predicted genetic advance. This indicated ample scope for selection. Subsequently, 15 lines selected on the basis of 4 criteria, viz, selection index, highest predicted genetic advance for yield (SC-**I**), rank total of different characters (SC-II), single plant yield (SC-III) and plot yield (SC-IV). The relative efficiency of the selection criteria was assessed by comparison of group mean yield and rank correlation. In both cases, the order of superiority of the criteria was SC-I>SC-II> SC-III>SC-IV. However differences, if any, were marginal (Devkota and Mahopatra, 1991).

Correlations

Bhagat *et al.*(1972) observed significant association between yield and number of productive tillers and days to heading. Number of fingers per panicle and finger length showed moderate association with yield. Plant height was negatively associated with number of tillers and grain density. Presumably, dwarf variety with a combination of more number of productive tillers and grain density, could be an ideal plant ideotype for improving grain yield (Bhaskariah and Mallanna, 1997).

However, Chaudhury and Acharya (1969) found negative association between grain yield per plant and days to heading. This could perhaps be an indication that plant height, number of tillers, finger number and finger length could hold the key for higher yield.

In a study involving 50 genotypes at Coimbatore (Dhanakodi and Chandrasekharan 1989)found that days to 50% flowering and plant height were significantly correlated with fodder yield. High heritability and high genetic advance for green fodder yield and number of leaves per plant indicated additive gene effects. Green fodder yield was positively and significantly correlated with all the traits both at the phenotypic and genotypic levels. Path-coefficient analysis revealed that plant height, number of leaves per plant and leaf weight per plant had the greatest direct effect on green fodder yield (Ramasamy *et al.,* 1991).

Thakur and Saini (1995) showed days to germination, days to flower and days to maturity were negatively associated with seed yield. In addition, path analysis indicated the importance of tillers per plant. Marimuthu and Rajagopalan (1995), while analyzing 11 yield components in 46 land races, found that seed yield per plant, days to 50% flowering, days to maturity, number of leaves per plant, and plant height had direct effect on harvest index. Further, Marimuthu *et al.* (1997) observed that correlation coefficients derived from data on 8 quantitative characters in the F_2 progeny of 4 finger millet crosses, grain yield was positively associated with its component characters in the descending order: ear weight> number of productive tillers> finger number> finger length> days to 50% flowering> 1000 grain weight. Ear weight, number of productive tillers and finger length showed positive direct effect on grain yield.

Basavaraj and Sheriff (1992) observed that data on yield components from F_2 populations of two inter-varietal crosses, correlations between generations were non-significant for grain yield in both the crosses. However, the selection indices from F_3 generation was the best indicator for indirect selection for grain yield. In F_2 populations of 4 crosses, information on phenotypic correlation coefficients and the direct and indirect effects of characters on yield was elicited from the data on five yield and yield related characters and blast severity. The number of productive tillers per plant showed the highest direct effect on grain yield. All the 4 crosses revealed a significant negative association on finger blast with days to 50% flowering and plat height (Ravikumar and Seetharam, 1993).

Correlation studies on 10 yield components in 21 divergent genotypes grown in Sikkim revealed that number of tillers per plant was considered the most important yield contributing character. Shanthakumar and Gowda (1997) observed that grain yield was positively associated with ear weight per plant, productive tillers per plant, fingers per ear and grains per centimeter length of finger. Path analysis indicated that ear weight per plant had the greatest direct effect on grain yield.

Bandyopadhyay (1998) studied correlation coefficients and path analysis in 27 varieties at Garhwal region of Himalayas and found that shortening the duration of grain filling and enhancing the harvest index would have greater relationship with production at higher altitudes.

Study of 37 genotypes by Bedis *et al.* (2006) indicated that days to flowering, days to maturity, plant height, main ear length, and number of fingers per ear and fodder yield were positively correlated with grain yields. However, Anantharaju and Meenakshiganeshan (2005) showed that grain weight was positively and significantly correlated with number of productive tillers and culm thickness. Number of leaves had moderate direct effect on grain yield. Finger length had high indirect effect on grain yield through number of leaves and days to 50% flowering.

Genetic variablity, correlation and path analysis studied in 29 genotypes by Bendale *et al* .(2002) had shown that grain yield per plant had significant positive correlation with days to emergence of fingers, days to maturity, finger length, weight of grains per main earhead and straw yield per plant.Grain yield per plant indicated positive and highly significant correlation with straw yield per plant, harvest index and weight of grains on main earhead at phenotypic and genotypic levels. Under mango-based agro-forestry system, path analysis indicated that finger length, harvest index, number of fingers on main earhead and straw yield per plant had direct positive effect on grain yield at genotypic level (Shinde *et al.*, 2010).

Impact of Environment on Variability Pattern

The significance of the components of variation, heritability and predicted genetic advance in respect of yield and yield attributes has been sufficiently emphasized. Such estimates are likely to give an insight into the direction of the characters under consideration to advance through breeding processes. However, the preciseness of the values would depend upon the extent of stability with which the characters react to given environmental changes. There is enough evidence that most of the characters have been very much biased by the genotype x environmental interaction. To understand the real genetic worth of the character, it was suggested to eliminate the interaction component from the gross variance.

The data relating to 22 genotypes tried under three environments (Kempanna *et al.* 1971) were subjected to combined analysis of variance in accordance with procedure outlined by Panse and Sukatme (1964). Pooled error mean sum of squares was calculated by using formula $S^2= si^2/n$ in respect of the characters with which the errors between the environments did not vary significantly. However, with the characters having heterogeneous error variance, the combined analysis was carried out by the method of weighted analysis of variance after testing for significance or otherwise of the genotype (varietal x environmental) interaction. The formula used was $Wi\text{-}r/si^2$, where Si^2 is the error MSS of the 'i th' environment, 'wi' is the corresponding weight and 'r' is the number of replications. This way, the variety mean of each environment was weighted with weights inversely proportional to the error variance of the means. This is expected to result in greater weights that would make the values more precise.

In this study, the error variance of the height of the plant and the total grain-bearing area were found to be homogeneous and, therefore, pooled analysis of variance was carried out. The interaction component (genotype x environment) was not significant when compared with the pooled error variance of the three environments. So the interaction and the pooled error were combined to arrive at the precise estimate of error for testing the differences in environments as well as in varieties.

The other characters, viz, yield, days to ear and tiller number showed their errors to be heterogeneous and the interaction (GxE) was highly significant. Thus the weighted analysis was carried out. The results of the combined analysis of variance ware:

Source of Variation	DF	Plant Height	Days to ear	No.of Tillers	Grain bearing area	Yield per plant
Environment	2	1136.16 (19.32)	1088.63 (51.33)	41.86 (52.49)	1013.47 (33.78)	594.29 (78.07)
Varieties	21	1521.79 (25.88)	261.86 (12.35)	1.89 (2.37)	533.66 (17.79)	59.52 (7.82)
Environment x variety	42	53.17 (NS)	21.21 (H.S)	0.80 (H.S)	29.89 (NS)	7.61 (H.S)
Pooled error	189	60.06	----	------	--------	-----
Combined estimate of interaction pooled error in the absence of interaction	231	50.80	-----	------	------	-------

Note: Figures in the parenthesis indicate 'F' Values
Source: Kempanna (1975)

Combined analysis of variance indicated the differential influence of environments on the development of all the five characters through significant variances. The environmental effect was, however, maximum on height of the plant, days to ear, and total grain-bearing area. It was moderate with yield and least in respect of tiller number. The variances due to genotype x environmental interaction were significant only with three out of five characters, viz, days to ear, tiller number and yield. But the interaction component seemed to be very high with days to ear, moderate with yield, and least with tiller number.

Components of variance and other heritability parameters after eliminating the interaction component

Character	2P	2g	CV	GCV	Heritability %	Genetic advance	Genetic advance in percent of mean
Plant height	425.55 (584.57)	365.75 (524.51)	26.25 (29.68)	24.29 (29.29)	86.15 (89.99)	36.57 (44.05)	46.57 (57.10)

Days to ear	81.37 (104.50)	60.16 (98.99)	13.38 (14.86)	11.50 (14.44)	73.93 (94.12)	15.98 (19.64)	23.69 (28.99)
Tiller number	1.07 (2.28)	0.27 (0.84)	23.82 (24.66)	14.19 (22.17)	25.47 (48.06)	0.54 (0.98)	14.75 (37.19)
Grain-bearing area	155.91 (220.34)	125.91 (190.32)	40.80 (48.16)	36.67 (46.37)	80.76 (85.09)	20.77 (25.97)	67.87 (84.64)
Yield of grain per plant	20.59 (33.04)	12.98 (19.13)	41.57 (53.72)	33.01 (48.45)	63.03 (64.10)	5.89 (7.03)	53.97 (83.36)

Note: Figures in parenthesis indicate the mean over three environments.
Source: Kempanna (1975)

Comparision of the ultimate components of variance after the elimination of interaction component from the total variance with the average of individual environments revealed the occurrence of interaction with all the characters. But it varied in degrees between the characters. Height of the plant topped the list in regard to phenotypic (2p) and genotypic (2g) variances. Next in order was the total grain bearing area; days to ear was moderate. Yield had relatively low values.

The coefficients of variability were nearly the same for yield and grain-bearing area. But the effect of interaction seemed to be more on the yield than on the latter as the value representing the coefficient of genotypic variance in regard to yield was reduced more than that of grain-bearing area. However, height of the plant and tiller number had moderate values in regard to CV and GCV. Days to ear showed the least value.

Even heritability values and predicted genetic advance were affected by the GxE interactions. The maximum variability was characterized by height of the plant to be followed by grain bearing area and days to ear. But it was moderate with yield and abnormally low with tiller number. It was apparent that the most affected by interaction was tiller number and this was closely followed by days to ear. However, the yield was least affected. The highest genetic advance was predicted for grain-bearing area with the yield following it. However, the yield was most affected by the interaction effect. But the least genetic advance was with tiller number, although the quantum of interaction component was not as much as that with yield. Days to ear was least influenced by the interaction.

Inter-environmental differences were indeed apparent. Kharif rain-fed environment was not good for most of the genotypes as the varieties were not uniform in their response to environmental changes. And their inconsistency was not so very wide-spread as to involve the phenotype as a whole. For only three characters: days to ear, tiller number and yield showed significant variance due to G x E interaction. Thus the greater amount of interaction with tiller number indicated its unstable nature and consequent less selection value for improvement. Interaction was moderate with yield and the least with days to ear.

It was shown earlier that cultivation system predominated the seasonal effects in influencing the components of variation. Although, it was evident in this investigation too, the probable impact of other vital environmental factors like years, locations and different days of sowing cannot be underestimated. However, Atwal and Singh (1966) opined that contribution by years to variance was not so much as it was by locations and sowing dates. So from this premise, it was possible to quicken the pace of improvement by including all the possible environmental factors in a relatively shorter span of time irrespective of number of years.

The significant outcome of this study, however, was that total grain-bearing area and grain yield had shown fairly high heritability values and genetic gain inspite of high GxE interactive effects (Kempanna, 1968 and 1975).

Mahato *et al*. (2000) found that the Genotype x Environment interactions with all the 5 characters in14 varieties tried under 4 environments were found significant. Most of the characters were governed by non-linear components of environment, except plant height and number of tillers per plant.

Misra *et al*. (2009) reported that multilocation yield trials on late duration (106 to 125 days) varieties were conducted under early and late transplanting conditions at Bhubaneshwar and early direct-sown condition at Berhampur in Odisha during kharif seasons of 2004 to 2006. GxE interaction analysis of grain yield in "Additive Main" and Multiplicative Interaction (AMMI) model, showed differential interaction of the genotypes under 3 planting conditions. IPCA-1 exhibitted 93% of G x E interaction. AMMI G x E interaction showed that the varieties OEB.56, OEB.71 and VR.822 had high mean and positive interaction, while PES.110 had high mean and very low interaction. On the basis of AMMI-II predicted yield, the genotypes OEB.56 and OEB.71 were better suited for early transplanting at Bhubaneswar and for early direct-sown condition at Berhampur. This indicated that these genotypes were suitable for early cropping, but not for late cropping. The genotype PES.10 showed better adaptation to both early and late transplanting conditions at Bhubaneshwar. But not for direct-sown condition. Six other genotypes showed specific adaptation to single environment only; of which Chilka ranked first under late transplanting at Bhubaneswar and VR.822 ranked first under early direct-sown condition at Bhubaneeswar indicating its specific adaptation.

Five varieties with erect leaf habit and 4 high yielding normal leaf habit varieties at 3 crop densities were studied by Marimuthu *et al.* (1995) at Paiyur in Tamil Nadu during Kharif season of 1991. Analysis of variance of grain yield showed significant effects of genotype, environment and GxE interaction. Erect variety TNAUS and normal PR.202 were found most adaptable to poor environments, while all others, except erect IE.252, were adaptable to favourable environments. In general, all the varieties were sensitive to high crop densities, irrespective of plant habit.

Twenty five genotypes were evaluated for 5 characters at Pune by Patil (2007). The pooled analysis of variance showed differential behavour of genotypes over environments. None of the genotypes was stable for all the characters. The genotypes EC.138375 and AKP.1 possessed high mean performance together with greater than one regression coefficient indicating their suitability to favourable environments and the variety Maduva for unfavourable environment.

GCA effects of parents and non-significant SCA effects, were suggested for recombinant breeding to develop tolerance to saline condition.

Combining ability and heterosis

Combining ability was studied by Gurunathan *et al.* (2006) in 21 hybrids for 8 yield characters together with the quality parameters. Analysis of variance revealed the predominance of non-additive gene action for all the traits. Among the parents, GPU.26, PES.400 and DPI.2011 could be utilized for improving yield contributing characters such as productive tillers per plant and finger length since they recorded high *per se* along with general combining ability effect (GCA). CO.9 and TNAU.946 could be used for improving proteine content. But for improving calcium content the cross CO.9 x GPU.28 was found the best. Similarly, Co.9 x PES.400 cross was the best for early flowering and grain yield. This indicated that pedigree breeding could result in developing varieties for both yield and quality.

Out of a total of 21 hybrids derived from 3 x 7 tester mating for studying heterosis relating to 10 traits, some crosses like Indaf-11 x DPI.2011 and CO.9 x PES.400 for grain yield and CO.9 x CO (Ra) 14 for protein contentCO.9 x TRY.1 for clacium content were found superior. These cross combinations could be utilized for recombinant breeding to incorporate these characters.

Sumathi *et al.* (2005) studied combining ability and heterosis in 15 F_1 hybrids involving 8 parents and found that non-additive gene action was found to be responsible for significant variation among all crosses for all the traits. This was due to higher magnitude of variance arising out of specific combining ability (SCA) than to general combing ability (GCA). CO.13 was found to be the most desirable female parent with positive GCA effects in respect of grain yield and number of fingers per head. A poor correlation was observed between mean performance of parents and their GCA effects. Thus selection of parents for hybrid development should be largely based on GCA effects. CO.9 x GPU.28, CO.11 x TNAU.9567, CO.13 x TNAU.956, CO.13 x GPU.28 and CO.13 x DPI.2011 with significant positive specific combining ability (SCA) were specific combiners for grain yield. The magnitude of heterosis for grain yield per plant ranged from 5.81 to 48.85% over standard CO.13. In general most hybrids involving one parent with good GCA effect showed higher SCA effects and standard heterosis for grain yield. This suggested that parental diversity for combining ability was necessary for greater manifestation of heterosis.

Gupta and Kumar (2009) studied 6 F_1 hybrids involving 5 varieties and found 2 crosses, S. 81-10 x CO.8 and CO.8 x IE.28 were the best for higher heterosis for grain yield from main spikes. The other yield components suggested were length of main spike and number of panicles per plant.

Shailaja *et al.* (2009) studied the response of 6 x 4 line x tester hybrids for determining the degree of combining ability for 10 quantitative characters and Na: K ratio. Variance due to SCA was higher for all the characters signifying additive gene action. On the basis of *per se* performance on GCA effects, GPU.28, C0.11 and VI.149 were identified as the best combiners for a majority of traits including grain yield per plant and Na+ : K + ratio. Depending on *per se* performance and standard heterosis, hybrids between GPU.28 x CO.13 and CO.12 x TRY.1 were found promising for grain yield. Based on significant GCA effects of parents and non-significant SCA effects, its was suggestal for recombinant breeding to develop tolerance to saline condition.

Genotypic variation in inter specific crosses in ragi

Gowda *et al.* (2008) analysed the F_2 population of three crosses involning Indaf.8, HR.011 and PR.202 of *Eelusine coracana* as female parent with the exotic species *Eleusine africana* as the male parent to investigate the nature of genetic variability and character associations among yield and yield attributes. Considerable variation was observed for all the quantitative characters. The characters like culm thickness, flag leaf length and width, peduncle length, finger length and width, test weight and grain yield showed high heritability and genetic advance. Grain yield was positively correlated with culm thickness, days to maturity, finger length and width and test weight. So it was suggested that selections in early generations for these characters might result in some useful recombinants for improving yield in ragi.

Genetic variability, character association and path-coefficient studies were made in two inter-specific crosses involving popularly cultivated varieties of *E.coracana* (HR.911, and PR.202) and exotic species *Eleusine africana* and analysed their F_2 segregating populations for yield and yield components (Shet *et al.,* 2010). It was observed that the hybrids were intermediate for productive tillers, finger length, finger number and days to 50% flowering. But, pollen fertility was low. PCV and GCV values were high for grain yield per plant and finger width and low for plant height and days to 50% flowering. But it was moderate by low for all other characters. High broad–sense heritability accompanied by high genetic gain was observed for plant height, finger length, test weight and grain yield per plant. However, grain yield per plant had recorded highly significantly positive correlation with finger width and test weight. The path-coefficient analysis in F_2 populations indicated that productive tillers per plant had the highest positive direct effect following finger width and test weight and grain yield, while finger number showed low positive direct effect on grain yield.

Breeding

Breeding is an important component of all the crop improvement programmes and so is with finger millet or ragi too. Despite being one of the most ancient crops in the world and occupying a critical position in arid agriculture of Africa and Asia, its cultivation remained primitive as there had been no conscious efforts at improving the status of the crop through organized research and development. This fact has been very well elucidated in the statement made by Prof. Katrien Devos (2005) of Georgia university, USA that: "the research on finger millet today is where the state of research was with wheat in 1890". This speaks volumes about the obvious state of research the crop had received over the centuries. Yet it had managed to sustain itself as one of the contributors to the world's food grain resources. It has been mainly because of its highly drought tolerant capacity and ideal food and nutritional properties it has possessed.

First-ever attempt at improveing the crop was initiated by Dr. Leslie C. Coleman in the then Mysore state (now Karnataka) in India by about 1900 AD. He made several collections of finger millet or ragi endemic to the states of Mysore and Madras province (now Tamil Nadu) in South India and studied the variability pattern at Hebbal, Bangalore. From this initial attempt, he identified 7 different types based on earhead shape and colour. Some were having long and open earheads with greem colour. While others had small, closed, compact purple pigmented earheads. This study had led him to isolate and develop a variety H_{22} selected from the bulk of the locally cultivated, non-descript variety Madayyanagiri. It was a tall open and purple-pigmented variety having a better yield structure than its parental stock and was found suitable for dryland cultivation. It was released in the state of Mysore in 1922 (Coleman, 1922). It had remained as a variety for a pretty long time.

Later, Narasimhan and Iyyengar (1992) identified another variety K.1, which was dwarf in stature with compact earhead. It was found suitable fo "Kar" tract (sowing in April-May) as against the main season crop from June to October / November At the same time, Tamil Nadu developed and released two varieties CO.1 and CO.10, which combined good yields with better protein content.

These were all pureline selections isolated from the locally cultivated bulks.. Hybridization was difficult with the crop as the florets in the

spikes were small and embedded in the densely crowded spikelets. Emasculation and pollination were rather difficult. Several attempts made at easing the situation by manipulating the floral structures through hot and cold treatments of florets ended with no relief.

However, Rangaswamy(1934) perceived that there could be a possibility of some chance cross-pollination occurring in nature and if so, it could be taken advantage of. Thus he suggested a concept of "**Contract System of Breeding**". This novel method involved in tying together of the earheads of the two selected varieties, cover them with grease-proof paper bags, collect the seeds from these earheads after they mature, raise the seedings from such seeds and make a selection of any variants occurring in nursery. If these variants (off-types) had shown any cross combinations of the characters found in the two varieties, regard them as the products of chance cross-pollination and select them and process further as per normal standard practice. Indeed, it was a hit and miss method and the progress was rather slow.

Nevertheless, a few popular varieties like *Purna, Annapurna and Cauvery* were evolved at Mandya centre through contract breeding system and released for cultivation. Variety *Cauvery* was suitable fo dry land cultivation, while *Purna* and *Annapurna* were found suitable for both dry and irrigated cultivation. Perhaps, following the "contact breeding system", Lakshmanaiah in 1970s developed a series of *Indaf* varieties using Indian and African genotypes in cross combinations. They had a very high yiled potential and replaced the earlier varieties. These varieties had brought a paradigm shift in ragi cultivation scenario in India.

Inspite of this spectacular achievement, the proof of genetic basis for "Contact Breeding System" was yet lacking. Fakrudin and his associates (1998) investigated this problem by tying together a purple-pigmented variety Indaf.9 and a green-pigmented variety GPU.28 and the resultant seedlings raised from these seeds showed 21.9% purple-pigmented and 1.9% green-pigmentated. Another set of 4 varieties (Indaf.5, GPU.26, GPU.28 and IE.2885) with green-pigmentation were brought together with another set of varieties (IC.1012, Indaf.9, KM.232 and IE.2912) with purple-pigmentation and the usual procedure was followed. The results showed that GPU.28 and Indaf.9 combination had the highest percentage of 21.9% of crossing and the lowest percentage of 1.9%. In another cross involving IE.1013 and Indaf.5 the crossing percentage was 12.82%. This proved three points that (1) natural crossing did take place in nature, (2) but it was genotypically controlled and (3) “Contact Breeding System” could be an alternative to standard hybridization technique to breed varieties in finger millet or ragi not withstanding its hit and miss nature and slow progress.

A pre-requisite for aggressive varietal breeding is the availability of a wide spectrum of genetic variability. Kempanna (1968 and 1975) screened 78 accessions from African collections of germplasm at Hebbal, Bangalore and found 3 cultures HES.927 (now IE.927), HES.929 (now IE.929) and HES.974 (now IE, 974), which were having very high yield potential. But they could not be introduced into cultivation directly as they were highly photosensitive, size of the grains was uneven and the stem was very thick, which affected the straw quality. Inceidently, straw is an important byproduct as fodder for the working animals, which could not be sacrificed.

These cultures were extensively used in breeding programmes both at Hebbal (Bangalore) and Mandya centres (Karnataka). The first-ever Indo-African variety HR.374 was developed, which was a cross between EC.4840 x HES.927 (now IE.927). This was a very high yielder. It was released for cultivation in Karnataka in 1997. Another variety HR.911, a cross between UAS.1 x IE.927, was adaptable to both kharif (June-october/November) and summer (February-May) seasons and was released for cultivation during 1985 (Gowda and Shariff, 1986).

By the middle of 1960, a devastating disease outbroke in Karnataka, which destroyed the entire crop for two years. It was diagnosed as a

disease complex involving blast (*IMagnaportha griseae*), Helminthosporasasis *leaf spot and* Sclerotium *it together with some physiological disorders. Govindu et al.* (1972) screened a total of 483 accessions at Hebbal and found 153 of them were moderately resistant. Genotypes from African collections IE.927, IE.929, IE.922 and IE.978 had potential for high productivity besides resistance to blast. Further, Mallanna (1977) found that accessions CO.7, IE.779, EC.4840 and EC.4847 were the best combiners with African genotypes for the improvement of tillering pattern, plant type and photosensitiveness. Additionally, cultures like PR.202 and IE.927 had combined resistance to both blast and *Scleratium* wilt diseases.

Apart from yield and disease resistance, was also found important for protein content (Kempanna, 1968 and Mallanna, 1969). Mahudeshwaran *et al.* (1972) observed that ragi, besides crude protein and fat, was also rich in vitamins and minerals. Hybrid CO.9 (white-grained type) was developed by crossing EC.4336 x PLR.1, which had a high percentage of protein at 8.06 to 11.73%. It was higher than that in brown ragi varieties. Another dwarf variety *Hamsa* with high protein content was developed in white ragi category. But it was not preferred by both consumers and farmers. However, it was crossed with a brown-seeded variety *Purna,* an already improved variety, and developed a new variety with high protein content. It was reported that one of the derivatives of this cross had high percentage of lysine upto 5% in its protein as against 3.4 to 3.8% in original *Purna variety.*

At Mandya centre lakshmanaiah in 1970s and 1980s extensively used IE.927, IE.929, IE.980 R and developed a series of **Indaf** varieties with high yielding ability. Indaf.1 was more suitable to kharif season and Indaf.5 for summer season, Indaf.9 was good for late kharif. subsequently, Indaf.1 and Indaf.5 were replaced by a better variety Indaf.8, Indaf.7 was released for rabi season (Late kharif).

Advanced varieties like ELC.4, PR.202 and PES.110 were evolved by Singh and Arya (1987-88) in Bastar district of Madhyapradesh (now Chattisgarh), India and released for cultivation in 1991. These varieties produced yields of 2,29, 2.02 and 1.92 t/ha, respectively and replaced the local varieties like BK.7001 and BK.7004.

Gowda *et. al*. (1988) developed another variety from a cross between PR.209 x IE.927, which had high yield potential in respect of both grain and straw besides tolerance to drought and lodging. It was released for transitional zone in southern Karnataka. To improve grain quality with high protein, a variety *Hamsa* was crossed with brown-seedded variety IE.927 and developed Indaf. 11 with better protein quality. In extensive field trails for 3 years during 1981 through 1984, three new varieties HR.911, Indaf.8 and Indaf.5 were developed, which had given the yields of 3.90, 3.48 and 3.80 t/ha, respectively.

Tyagi and Rawat (1989) evolved two varieties Pant Mandua.3 and PES.110 in Uttarkhand state of India in the Himalayas. Both were tolaerant to leaf, finger and neck blasts. The former matured in 95 days. It was 80-85 cm tall with compact and curved spikes and the seed was light-brown in colour. It gave an yield of 2.8 t/ha. The variety PES.110 matured in 115-120 days, had medium sized top curved spikes and bold grains. Both were suitable for the hill climate.

Sundareshan *et al*. (1988) reported a variety CO.12, which was a selection having medium duration and matured in 85-100 days with an average yield of 3.93 t/ha besides tolerance to blast disease. It was suitable for Tamil Nadu in India.

Byregowda and Viswanath (1988) developed a variety HR.391 with an yield potential of 3.0 t/ha. It was suitable for rained cultivation in dry belt of Southern Karnataka. It matured in 118-120 days.

P.1462703 was a selection from germplasm bank, registered in Zimbabwe in 1986. It gave a grain yield of 3.46 t/ha, matured in 87 days and had a medium grain size and seed dormancy of 7-8 weeks after harvest. It was good for malting (Guptha and Mushange, 1986).

Mushange *et al.* (1992) released one of the early maturing varieties in Zimbabwe. It took 76 days to reach 75% heading as against 87 days

of the locals. It was brown grained with an yield of 2.30 t/ha. It was good for brewing.

Gowda *et al*. (1995) developed a dual purpose variety MR.2 for Southern Transition belt of Karnataka. It was an hybrid derivative of PR.202 x IE.927, developed at Mandya centre. It had superior grain yield together with tolerance to drought and lodging.

Mushange *et al.* (1992) developed FMVI variety and recommended for cultivation in Zimbabwe. It was a selection from germplasm bank of Zimbabwe and had an yield potential of 2.30 t/ha and took 72-88 days to mature. Grain was brown in colour and good for brewing.

Devendramohan (1993) developed a variety VB.149 from a cross between VL.201 x IE.882 and it was a tall variety, flowered in 65-69 days and matured in 102 days. Recorded 16.7% more yield than mid-late variety HR.374. It was developed at Directorate of Wheat Research at Karnal in Haryana in North-West India.

A variety KAT/FM.1 was developed by M' Ragwe and Watson in Kenya. It matured in 90-115 days and was blast and drought resistant. It could have been cultivated right from an altitude of 50 meters to 2000 meters. It had a potential yield of 1.4 t/ha in semi-arid areas of Kenya.

Mnenyembe (1990) tested 25 selections at 7 locations in malawi during 1974-75 and identified a selection 334 with 2.5 t/ha yield. Additionaly, another set of 25 cultures were tried over 9 sites and found that Selection 516 and Selection 334 were top yielders in the first and second years. Further, lines 40, Mavoli and Doplopa outyielded most of the late maturing varieties. In this trial, highest yielders were 1092, 227, 203 and Katubatuaba. Among the pigmented varieties, lines 517, 526, 334, 398, 510,494,502, 514 and Katubatuba were the highest yielding. The Selections 517, 526, 334, 510, 494, 502, 546 and 554 yielded more than 3.00 t/ha. The crop, when drill-sown at 25-30cm spacing in level field was superior to broadcasting and or sowing or planting on ridges. It responded well to N and P fertilization but not to K fertilizer.

Advanced early maturing varietal trials involving 25 Selections were conducted at 4 locations in Zambia by Gupta *et al*. (1989-90) under collaborative programme. The results showed that the variety SDRM.3 was the highest yielder with 4.86 t/ha, which accounted for increase of 42% over the check variety. While this was the top yielder in Zambia and Malawi, the variety SDRM.937 was the best in Zimbabwe. Based on the overall mean yields of 5 locations, SDFM.217 with 3.0 t/ha was found the highest yielder. It was also so in Tanzania and Zambia. Whereas in Malawi, it was SDRM.990. But in Zimbabwe, SDFM.113 and SDFM.723 were found promising.

Bhat and sheriff (1994) studied heritability and genetic advance in F_3 segregating generations of two crosses MR.6-27 x Indaf.9 and MR.911 x HR.7-30-2. And observed that simultaneous selection for number of fingers per panicle, ear weight and 1000 grain weight could advance the grain yields in the first cross, while ear weight and 1000 grain weight did so in the second cross.

Eleven ragi varieties evaluated at Hagari Research Station in Bellary district of Karnataka during 1992-94 by Ibrahim *et al*. (1998) led to the identification of two varieties KM.221 and Rau.8, which had the yield potentials of 3.9 and 3.5 t/ha, respectively. The difference between the two was 6-7 days in terms of maturity. However, Rau.8 matured 10 days earlier than the locally cultivated variety Kudlagi Local, which had and yield potential of 3.2 t/ha.

Gowda *et al*. (1999) tried F_2 and F_3 populations of the crosses involving lines differing in protein content and blast (*Magnaportha grisae*) disease resistance to identify the recombinants having good yields and blast resistance. But the relationship between the three characters turned out to be negative. Nevertheles, few recombinants having relatively high level of protein with moderate to high levels of resistance to blast combined with reasonable levels of good yields were isolated.

Patil (2007) at Pune (India) compared yield and quality of 9 genotypes and found significant differences between them in terms of germination percentage, root and shoot lengths, seedling weight (dry), vigour index, 1000 grain weight and grain yield. The highest grain yield and other good food quality parameters were observed with the variety GPU.34 followed by MR.16.

A total of 16 cultures were evaluated at Mandya centre (Karnataka) by Ravishankar *et al*. (2004 b) for yield and other yield attributes. Out of these, the progenies of the crosses PR.202 x GE.1409-1-6 and PR.202 x GE.1409-2-5 were significantly superior in respect of number of fingers per ear, grain weight per ear and earhead length and they matured in 114 days. However, another culture MR.23-11-5 took 120 days to mature (long duration). But it was significantly superior in respect of number of fingers per earhead, earhead weight and grain weight per earhead. However, 1000 grain weight was the same in all the three maturity groups.

Another set of 11 stabilized cultures in different maturity groups having good yields combined with finger blast resistance were evaluated at Mandya centre. Cultivars MR.33 (long duration), KMR.9 and KMR.3 (medium duration) were found significantly superior to their peers (Ravishankar et al. (2004 a). Besides better grain and straw yields, they were tolerant to leaf, neck and finger blast. However, the early maturing cultures like KMR.8 and KMR.4, though highest in grain yields, were moderate in their response to leaf, neck and finger blasts.

The relationship between cold-stress effect and grain yield and yield components was investigated by Bandyopadhyay (2009) at Tehri-Garhwal in Uttarkhand state in Himalaya, India. Seeds were sown in June and the plants were exposed to cold-stress at maturity. The inpact of temperature effects on days to flowering and maturity was determined by correlation analysis. It indicated that number of seeds per spikelet had significant positive contribution to yield during the second and third years of the trials. Correlation study indicated that the sensitive cultures to different environmental regimes had expressed some unexpected and unexplainable character manifestations, which were not there earlier. It was, indeed, a surprise beyond standard scientific explanation.

Performance of six F_1 hybrids involving 5 varieties was analyzed by Gupta and Kumar (2009) at Kanpur, Uttarapradesh, India and found that two crosses S.81-10 x CO.8 and CO.8 x IE.28 had higher grain yield per main spike than their respective better parents. Longer lenghth of main spike, higher number of grains per spike and higher number of panicles per plant were attributed to the manifestation of heterosis. The yields of these crosses were better than the locally cultivated variety T.36 B.

After 1970s, finger millet research in India was substantially strengthened under the all India Coordinated Small Millet Improvement Project under the aegis of the Indian Council of Agricultural Research (ICAR), New Delhi. Dr. A. Seetharam, the then Project Coordinator along with one of his collegue B.H. Halaswamy reviewed the varietal scenario in India right from the initiation of ragi research in India by Leslie C. Colemon in 1900 AD till 2003 and a comprehensive list of 88 varieties along with their salient features was published in the form of "Hand Book of Small Millet Varieties".

Additionally, another list of varieties developed and released for cultivation in India from 1918 to 2012 was compiled along with their vital characteristics by the present Project Coordinator Dr. Channabyregowda in association with his collegues in the Coordination Cell at the University of Agricultural Sciences, GKVK, Bangalore, India. This list contains 111 varieties and more up-to date. The details are in the statement (Annexed).

Ragi research in India has been more vigorously pursued from centres spread all over India under the All India Coordinated Project. The average yields under dryland conditions have almost touched two tonnes per hectare with the best in the country almost around 6.0 t/ha. The crop has been receiving a considerable "Public Policy Attention" as its grain is more nutritive and a health remedy against some of the worst degenerative life-style maladies. Even in Africa, its original home, where it had lost the area heavily during the Green Revolution Period, the revival process had begun. Unfortunately, the present status of the varietal resources in that country could not be readily accessed.

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PATTERN OF ADAPTATION

Adaptation as described by Lerner (1954), is the ability of all biological organisms to equilibrate their genetic constitution and resist sudden changes. It means that they adjust to variable conditions or to self-regulating mechanisms, which permit them to stabilize themselves in fluctuating outer and inner environments. It could be the same as the phenomenon of "**genetic inertia**" as proposed by Darlington and Mather (1949).

Finger millet or ragi is being cultivated all over India and some parts of Africa. Phytogeographical studies have indicated the distinctness of geographical regions with their own selective patterns of variation. The variability patterns, which obviously constituted the basis of general heterogeneity are, presumably, the outcome of interaction between the plant communities on one hand and the plant communities and the environment on the other.

Further, from ancient times, it has been a rainfed crop in relatively lighter soils. The advent of irrigated farming together with the photo-insensitivity of the species enabled its successful cultivation throughout the year irrespective of the seasonal variations. This has evidently been the ability of the species to make allowance for the obvious changes in agro-climatology.

It is true that genotypic differences do occur in nature for adaptability. But the main hurdle in the way of their exploitation for breeding is the lack of suitable parameters to measure the adaptability as such or, for that matter, the complexities of environments. However, the phenotypic stability test, suggested by Finley and Wilkinson (1963) is said to be effective as it is considered to provide a simple and dynamic interpretation to the problem of adaptation.

With this background, 22 cultures-12 from Bihar, 7 from Karnataka and 2 from Tamil Nadu regions in India and one from an African

region-were studied at Bangalore under three environments by Kempanna *et al*. (1971). The nature of environments were : I)-environment related to irrigated cultivation during summer (January to June), II)- environment represented by Kharif irrigated (June to December), and the III)- environment was cultivation during Kharif under rainfed condition. The data were collected on quantitative parameters like grain yield per plant, days to ear, tiller number and total grain yield per head. The regression coefficients were worked out for each of the varieties. The analysis of adaptation was made by the use of a two dimensional plot (Scatter diagram) in which the varietal means and the regression coefficients formed coordinates. Quantitative grading of the environments was done by a comparison of mean grain yields of all the varieties under three environments.

Analysis of variance revealed that the environments differed significantly between themselves in their impact. The impact of the III - environment was rather very poor because of its overall mean being roughly three times less than that of I- and II- environments. In a similar vein, varietal (genotypic) differences were also apparent. The regression techniques studied indicated the varietal yield responses to different environments. The variance due to genotype-environmental interaction was also highly significant. This was attributed to linear regression.

Regression coefficients varied greatly. Three quarters of the Bihar varieties showed the regression coefficient ('b' value) less than one implying that they possessed high average phenotypic stability, while the other quarter possessed average stability (b=1.00). Karnataka and Tamil Nadu varieties were found to be distributed between the high average stability (b=<1.00), average stability (b=1.00) and below average stability (b=>1.00) categories in the proportion of 3:4:2. However the African variety HES.927 (now EC.927) was having above average stability (b=0.83)

Regression coefficients and the varietal mean yields over all the three environments constituted two important indices to measure the varietal adaptabilities. The general interpretation was that the average stability (b=1.00) in conjunction with the average mean yields over all the three environments should provide the measure of average stability. Any deviation from this must, however, set standards for newer patterns.

Apparently, altogether five adaptability patterns were characterized by the entire experimental material (Fig….), They were **(1) Average adaptability:** it was a standard pattern involving regression coefficient around 1.00 and the mean yields approximating to the mean of three individual environments. In this, the change of environment, one way or the other, could hardly alter the already established yield position. From amongst the varieties tried, the variety *Hullubele* from Karnataka represents this category.

(2) General adaptability: Varieties having above average stability (b=1.00) together with significantly higher average yields, quality for this category. Among the varieties tried, HES-927 (now EC-927) from African region scores a grade to this category. The varieties under this category have so much flexibility as to balance against all the likely environmental fluctuations.

(3) Poor adaptability: Varieties, despite having high average stability (b=<0.001), come under this category because of their consistently poor yield structure. White-grained variety (peach coloured) *Majjige* from Karnataka featured under this class.

(4) Specific adaptability to high yielding environments: Below average stability and the yields around the overall mean under the low yielding environment were the characteristics of the varieties under this category. But with every change in environment for better, there was a progressive increase in yield such that they become the best yielders under more favourable environment. This was exemplified by a variety H_{22} from Karnataka.

(5) Specific adaptability to low yielding environments: This is the opposite of the 4th category. In that, phenotypic stability of the

genotypes was very high as the regression coefficients often approached zero. Whereas, their yields were either around or slightly above the mean of the low yielding environment. They appeared so rigid in their responses that they hardly changed their yield levels even with the change of environment for better. But the merit of such varieties is that they could produce some grain even under extremely adverse conditions.

In conclusion, 22 cultures tried, grouped themselves into 5 adaptability patterns in the proportion of 8:2:3:2:7. Obviously, the 1st and 5th adaptability categories predominated the rest. But compared to a huge number of accessions in the **Core Group** of 552 (Seetharam *et al.,* 2003) this is a miniscule now. Yet, it had displayed the trend that could be expected in terms of adaptability patterns inherent in the genotypes.

Similar assessments of the genotypes could be made on the basis of yield contributing characters too. Inter-environmental variation in respect of tiller numbers indicated that Bihar varieties tended to have more tillers than those from Karnataka and Tamil Nadu; whereas, the African variety, HES.927 (now EC.927) was having a minimum number of tillers. But Bihar and Tamil Nadu varieties were less stable than those of Karnataka and Africa. The highlight of this study, however, was the recognition of an African variety, HES.927 (now EC.927) with a remarkable combination of low tiller number and high average stability, which was a highly desirable feature of a general adapter.

In terms of grain-bearing area per head, varieties from Karnataka and Tamil Nadu had more than their counterparts from Bihar; but it was phenomenally high with an African variety HES.927. This apart, the grain-bearing area was negatively correlated with the phenotypic stability. This indicated the very high responsiveness of this character to environmental changes. Among the genotypes, HES.927 from Africa and *Annapurna* from Karnataka ranked first and second, respectively, in so far as their phenotypic instability was concerned.

With regard to number of days to flower, Bihar varieties grouped together in their stability index between less average and high average stability. Whereas, the varieties from the other three regions were almost homogeneous with high average stability.

Yield being a compound character, the necessity of analytical assessment of its component characters is emphasized to have a fuller picture about yield. Grain-bearing area and days to ear seemed to have positive relationship with yield, whereas the tiller number was somewhat dubious. There is a general tendency that heavy yielders are late in maturity and offer greater resistance to environmental fluctuations. Similarly, the high yields are linked with high grain-bearing area inspite of the fact that it was highly reactive to environmental fluctuations. This seemed to have been related to the cockscomb nature of the earhead that some varieties were characterized by. Yet the cockscomb genotypes like HES.927 (now EC.927), *Annapurna, Cauveri,* H_{22} and 348 were generally high yielders. This suggested the probable occurrence of some compensating mechanisms within as well as between plants to offset the likely negative effects on yield under different environments.

High yielding varieties under 2nd and 4th adaptability patterns, tended to have low tiller number, but showed remarkable phenotypic stability. This appeared to be a significant trend in the sense that by reducing the intra-as well as inter-plant competitions, it promoted greater productivity of the plant, besides, it also permitted higher plant populations per unit area, which is considered as one of the most direct ways of advancing the yield.

Finley and Wilkinson (1963) observed in barley that the varieties originating or bred for a particular agro-climatic conditions tended to converge together in their character combinations. The truth of it had been displayed by the varieties from Bihar. They were generally low yielders, but capable of adapting to low yielding environments.(Fig..). Such an evolutionary trend was explicable on the grounds that ragi in Bihar served agriculturally subsidiary interest with no or very little human intervention in the matter of varietal development. The pattern

of adaptability exhibited by this group of material did seem to be an end result of continuous struggle over a period of time in the course of evolution to acquire reasonable amount of innate capacity to balance against the environmental fluctuations.

The performance of a variety *Majjige,* Peach-coloured ragi from Karnataka was again an additional case in point. Despite its origin in the major ragi growing region of Karnataka, it exhibited poor adaptability to all the environments. The reason was obvious from the fact that it had never been considered as an agricultural variety in view of its peach-colured grain, which was not a preferred choice of ragi consuming populace. Thus its present status owed a great deal to the forces of natural selection with a little human intervention.

By contrast, Karnataka and Tamil Nadu varieties were more heterogeneous in their adaptability. It was possible due to the fact that they had been bread to suit varied agro-climatic conditions, which *inter alia* included cultivation systems (edaphic factors).

Das and Patnaik (1999) evaluated 8 micro-mutants of ragi under different environments comprising two sowing dates and four fertilizer levels. Stability analysis was done following linear regression, mean-CV scatter plot, ranking and MASEA methods. Variety Mut.16-4-2 was stable in the linear regression method, ranking method and MASEA method indicating its wider adaptability over other mutants.

In phenotypic stability analysis ,18 strains of white ragi under 6 different environments (two dates of sowing and 3 seasons) (Kharif 1988 and 1989 and rabi 1988-89) by Prusti *et al*.(1998) at Bhubaneswar showed significant G x E interaction for all the characters except effective tillers per plant. Among the linear and non-linear components of interaction, the former was predominant for effective tiller per plant, whereas the non-linear component was significant for grain yield and days to heading. But both were important for 1000 grain weight. In general, the genotypes with relatively high performance had possessed low stability. In a similar study genotypes showing general adaptability and specific adaptation were identified.

Five genotypes showed promise in terms of grain yield for moderate input management conditions.

Phenotypic stability for grain yield and its components in a study of 17 genotypes at 15 locations across India during 1989 by Ashalatha *et al.* (1998) through Eberhart and Russel method led to identify SR-SD-G-6-82 and TNA-321 as most stable genotypes to be included in the breeding programme.

In a study involving 19 white ragi cultivars with white seeded Indaf.11 and brown seeded GPU.26 and GPU.28 as controls across 3 locations, the G x E interaction was significant. But none of the genotypes were stable across the environments. However, genotypes IE.2835 and IE.2906 showed stability for grain yield and straw yield per hectare (Sonnad and Kumar, 2008).

In the initial screening of 15 early duration finger millet varieties through RAPD markers using 25 decamer primers of which nine primers, OPA-4, OPA-13, OPA-16, OPC-18, OPD-8, OPN-7, OPN-15 and OPN-16 showed polymorphic banding pattern for the genotypes. Total number of bands produced ranged from 2 to 9 per primer. The nine primers produced 60 amplification products, of which 9 were monomorphic and 51 were polymorphic. In order to study the relationship of presence/ absence of a polymorphic band with genotypic adaptation, 15 early finger millet genotypes were classified into '+' group for presence and '-' for absence of band OPA4~ 1800 bp, OPC12~900 bp, OPD8~850 bp, OPN7~2600 bp, OPN15~2500 bp, OPN15~900 bp and OPN16~2600 bp. The genotypes were also classified into high yielding (HY) and low yielding (LY) classes, two adaptability classes, specifically adapted to rich environments and specifically adapted to poor environments, i.e this experiment revealed that the presence of OPA4~1800 bp and absence of OPN 15~900 bp bands in finger millet might give some indication about specific adaptability of genotypes to poor environments. Absence of OPA4~ 1800 bp and presence of OPN 15~900 bp would indicate specific genotypic adaptation to rich environments. These findings might help to predict the genotypic adaptation of different genotypes before going for multiplication trials (Das *et al*., 2009).

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SEED TECHNOLOGY

Seed is a basic necessity of all agricultural production systems. Thus the economic prospects of the crop very much related to the quality of seed. There are several characteristics of the seed–physical, physiological and even both which play important role in determining the quality of seed. While most of them are good and beneficial there are few which have a negative impact on the quality. Detailed study of sum of them all together and working out the strategies to the neutralize the adverse impact of the latter constitute the subject matter of seed science or seed technology.

One of the most important character is germination, which is both physical and physiological. The good and healthy seed germinates with in 5-6 days from sowing. But it may not be always so. The initial setbook for this is the lack of sufficient moisture in the soil, particularly under dry farming situations. Many a time, it happens so even under irrigation systems where moisture is not limiting. This could be accounted for by many factors: Firstly it is a case of loss of viability due to the over age of the seeds, which varies from species to species and even varieties with in the species. It is a proven fact that prolonged storing and faulty storability are also important causes. Since finger millet is less vulnerable to storage pests, its contribution to loss of viability is rather minimal. Paradoxically, given all the ideal conditions, germination fails to occur. This is a physiological phenomenon called *dormancy*, which is inherent with the seed.

Dormancy is a characteristic feature of all the plant species. But the period of dormancy is variable. In certain crop species it is hardly few days between the physiological maturity of the seed and germination, while in others, it may be a few weeks to few months. Perhaps, it could be a genetic phenoman built into the seed by nature to tied over factors like drought as exemplified by pasture and forest species.

Kalappa and Prasanna (1993) studied 17 varieties of ragi for germination out of which4 varieties had germinated to the extent of 80% at two months after harvest. When tested again at 6, 7 and 8 months all showed a gradual increase in germination percentage. This is probably a typical case of varietal variation in finger millet. Seat of dormancy was often a matter of discussion. In some cases, hard seed coat or pericarp which is impervious to water to soak in might cause delay in germination. This was demonstrated by Sahoo (1994) in finger millet. Freshly harvested and shade dried seeds of 8 varieties with pericarp–intact and pericarp–free (removed) were tried and found that seed dormancy in pericarp-free seeds ranged from 14 days (cv.IE.723) to 4 days (cv.VR.427) while that with pericarp-on remained dormant 7-14 days more than the pericarp–intact seeds.

Seed size seed recovery vigour index and the Electric conductivity (EC) of the seed leachate also influenced seed germination and quality. Murthy *et al.* (1997) separated 15 varieties into two fractions: > 1.981 mm and <1.981 mm in size. The recovery from the former was in the range of 41.6 to 59.6%, while in the latter category it was from 40.4 to 58.4%. The third and the fourth fraction contained a mixture of abnormal brackish immature and broken grains. Seed recovery decreased with increase in screen size and seed size. Germination and vigour index increased with seed size. Seed leachate EC decreased with increase in seed size. Larger seeds recovered on larger screens were superior in quality. But the recovery is less. Thus it was concluded by Lokesh *et al.* (2000) that medium sizes screen (1.5mm) was more suitable for all observed seed qualities and seed recovery compared to 1.4mm and 1.3mm screen sizes, which were in vogue.

Investigating the effect of seed size on storability Lokesh *et al.* (2000) showed that the seeds of all the four varieties, viz, Indaf.5, Indaf.9, MR.1 and HR.911 retained germination percentage ground, were stored in cloth bags and kept under ambient conditions for 8 long months. Indaf.9 (75.7%) and Indaf.5 (75.5%) above minimum quality standards of 75% even after 8 months; where as MR.1 and HR.911

retained germination percentage ground 76.9% and 75.5%, respectively only 7 months only. At the end of 8 months, Indaf.9 recorded the highest germination percent and vigour index. Irrespective of the varities and seed sizes, the seed leachate EC increased as the storage period increased. Further seed leachate significantly increased as the seed size decreased throughout the storage period.

Continuing the studies, Lokesh *et al.* (2000) graded the seeds of 4 varieties into large (>1.6mm), medium (1.6 to 1.5 mm), small (passed through 1.4 mm but retained on 1.3mm size screen) and ungraded (control). Stored in cloth bags for 8 long months and frequently tested at 3,6,7 and 8 months interval. Germination percentage vigour index and seed leachate EC were found to differ significantly among the varieties and seed sizes. Nevertheless larger seed size lot had higher germination percentage and vigour index than the smaller sized seed lot, Indaf.9 with larger seed size had the lowest seed leachate EC.

Krishnappa *et al.* (2001) evaluated 7 varieties for seed quality characteristics. Highest percentage of 86% germination was recorded by GPU.26 and the lowest of 23% by Indaf.8. Fresh ungerminated (FUG) was the highest at 77% with Indaf.8 while the lowest of 13% was with GPU.26. There was a negative correlation between germination percentage and FUG. The vigour index was the highest at 168.00 in GPU.26 and the lowest at 30.0 with Indaf.8.

Seed dormancy in ragi was studied in 16 varieties at Bangalore by Narayanaswamy *et al.* (1987) and found the evidence of varietal variation: two varieties had 45 days dormancy, 7 varieties had 60 days, 5 varieties had 90 days and two varieties were having by 110 days dormancy.

The possibility of predicting the longevity of finger millet and Amaranthus seeds during storage was studied by Mutegi *et al.* (2001) in Kenya. Varieties KAT/FM .1 of finger millet and cruentus of *Amaranthus* hybrid–sub–species were stored in hermetically sealed, laminated aluminium foil packets for up to 252 days at different combinations of temperatures ranging from 15 to 40^{0}C and moisture contents of the seed ranging from 5.3 to 17.3% (fresh weight basis). Seeds were tested at different intervals. The results were that the viability declined rapidly at higher temperatures combined with high moisture content. With each of the varieties the estimated period of viability to fall to or below 50% decreased with an increased in storage temperature and moisture content. Viability constants for each of the two species seeds differed considerably in longevity. The concept of constants obtained here could be applied to predict storage life of seeds of the two species under short time to medium term storage conditions.

The effect of certain mild acids on the preservation of moist ragi grains was elucidated and found that 3% concentration of acetic acid prevented the growth and multiplication of all the microflora associated with grains except *Aspergillus fumigates,* which requiredmore than 3% concentration of acetic acid the grains remained viable over afterafter treatment with 5% acetic acid (Pande, 1986).

Seeds of two varieties were tested for germination in 3 media (between papers, on top of the papers and in sand) at 20^{0}C or 30^{0}C or at alternating temperatures (Kumar *et al.* 1990). Germination at 20^{0}C was higher than at 30^{0}C. Among the varieties, KM.13 showed that germination in between papers and on-top of the papers was similar. But it was higher than in sand where as the variety Nirmal gave the highest germination top-of-the paper at 20^{0}C.

The popularly held concept that certain biochemical changes do take place in the grains during storage was investigated by Sarloch and Gill (1992) by storing the hardened and pelleted seeds of variety CO.13 in cloth bags and 700 gauge poly then bag separately. On evaluation at monthly intervals, after 6 months of storage the hardened and pelleted seeds recorded higher values for all the biochemical properties which had negative correlation with germination electrical conductivity free aminoacids and fungal infection, whereas, lower value in respect of dehydrogenase activity had a positive correlation with germination.

Presowing treatment of seeds has been in vogue in some ragi growing areas particularly under dry farming situations, with a view to hasten germination and subsequent growth under possible depleting soil moisture conditions as an insurance against likely crop failure if the rains become erratic. Ragi seeds were treated with pure water (control), 1% Ca Cl, 2% polyethylene glycol (PEG 6000), 1% KH_2P0_4 and 0.1 ppm brassiosteroid (BR). Grain yields were more in all the treatments than in control (water treatment), but it was the highest under BR treatment (Nithila *et al.*, 2007).

Seeds of 3 varieties were unsoaked (control) or soaked in water at 0.25% Ca Cl_2, 100 ppm Na_2HPO_4 or 100 ppm KH_2 PO_4 and sown in sandy clay loams under rainfed conditions with a view to ascertain the impact on growth and yield (Maitra *et al.*, 1997). Varieties A-404 and EC. 50-90 had highest number of ears and greater finger length, respectively than Birsa Marua.1, A.404 gave the highest grain yield followed by EC.50-90 Presowing treatment with Na_2HP0_4 or KH_2P0_4 significantly increased number of ears/ plant, number of fingers/ ear, length of fingers, grain weight/ ear, 1000 grain weight grain yield straw yield and nutrient uptake compared with the control and watersoaked treatments.

Msuya (2004) observed that submerging or soaking the earheads before threshing retained higher germinability and germinated faster than dry–threshed seeds in Japan. However proper aeration of the seeds during submersion is a critical prerequisite for ensuring good germination.

Biochemical changes in germinating seeds under moisture-stress conditions of two varieties were studied by Sarlach and Gill (1992). Between the two varieties CO-10 was stress-tolerant, while PR.202 was stress sensitive. Seeds of both the varieties were germinated in different concentrations of PEG 6000 solution giving–0.1, –0.2 –0.3 MPa osmatic potential. Endosperm and embryonic axis protein content amino acid pool size and photeolytic activity and found that they were greater in the tolerant variety CO.10 than in the sensitive PR.202.

Effect of seed hardening and pelleting on storability was studied by Vigneshwari *et al.* (2006). There were 9 treatments. In general germination was found reduced under all treatments. Yet under calcium chloride and brasinolide, higher percentage of germination was found after 6 months of storage. It was also shown that hardened and pelleted seeds could be safely stored in polythene bags upto 2 months and one month in cloth bags. But brasinolide-hardened and calcium chloride hardened seeds germinated 75% upto 4 months in polythene bags and upto 3 months in cloth bags.

Punithavathi and Palinichamy (2003) reported that seed hardening and hardening-cum-pelleting with different treatments such as water hardening, 1% KCL, 1% $CaCl_2$, 0.5% KCL+0.5% $CaCl_2$, 1% leaf extract of *prosopis julifera* and 1% leaf extract of *Pongamia* glabra gave varying results. Seeds were successfully hardened by treatment with KCl_2 followed by pelleting with *Pongamia* leaf powder. The hardened and pelleted seeds could be stored upto 5 months with higher germination (83%) and seedling vigour compared with simply hardened seeds (75%).

The existence of allelopathic phenomenon and its influence on germination of seed and seedling growth in Eleusine coracana, cv. APK.2 were observed by Padhya *et al.* (1992). According to the study the leachates of senescing and freshly fallen leaves of *Eucalyptus globulus* affected germination and inhibited the growth of shoot and root. However the inhibitory effect was in direct correlation with the concentration of the leachates.

Effect of Soaking of leaf litter of *Khaya* senegalensis for leaf extraction after 1,2 or 7 days as well as the leachate concentration at 0,25. 50 or 100% were studied with reference to their effect on seed germination and seedling growth in finger millet by Rajesh and Vasudeva (2004). It was found that although germination, shoot and root length and vigour of the seedlings were decreased, the germination was more affected at higher leachate concentrations (50-100%). The leaf leachate slightly inhibited shoot elongation but stimulated root elongation. The combined effects of soaking in the leachate at 50% w/v was the most stimulatory. Shoot vigour index decreased in the presence of leachate at all concentrations. Soaking period and leachate concentration had higher inhibitory effect than the individual factores in blotter test. Of these 16 fungi, known pathogenic ones were *Botrytis*, *Cercospora*. *Furarium*, *Pyricularia*, *Macrophomina, phasiolina* and *Drechslera nodulosum.*

Even seed-borne fungi like *Magnaportha grisea, Cochiliobolus nodulosus, Bipolaris nodulosa, Fusarium species* and some cases of *Alternaria, Curvularia, Cladosporium* and *Aspergillus* were shown by Adipala (1992)in Uganda to impact germination of finger millet.

Additionally contamination of finger millet grains with *Bacillus cereus prior* to or during germination and its excessive growth led to the production of heat resistant toxins resulting in impaired grain germination. Strict manufacturing processes have to be followed in the food processing industries where germinated seeds were used as raw material. It was further pointed out that contamination levels of *B.cereus* in raw finger millet grains itself should not be allowed to exceed 100 CFG-1 (Kimanya *et al.*, 2003).

When seeds of finger millet were treated with *Fusarium oxysporum*, F,roseum and *F.moniliforme* not only germination of seeds but also root and shoot growths were affected (Biswal and Narain, 1991).

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CROP PRODUCTION

Eleusine coracana, commonly known as finger millet or ragi is a highly nutritious food and fodder crop, mostly grown in semi-arid and arid regions of Southern and Eastern Africa and India. Being a drought-hardy crop, its water requirement is very less ranging from 300-400 mm provided it is spread over the cropping period. In India, it is predominantly a dry land crop, grown during the monsoon season from June to October-November. It can also be cultivated under irrigation, mostly during post-monsoon period (rabi) and summer seasons. But, proportionately, it is a small crop relative to rainfed crop. It grows in all soil types except in deep black soils which are prone to water logging and saline-alkalinity. However, the red sandy loams are the best.

Under normal conditions, it is a highly productive crop because it belongs to C_4 type category of crops, which are characterized by an aspertate predominant photosynthesis. It implies that its productive efficiency relates to its economical use of carbon by eliminating the wasteful process of photo-respiration. Inspite of it, general yields of grain range from 2.8-5.4t/ha and straw yields from 9.3-23.7t/ha leading to low grain-straw ratios of 0.23 : 0.37. This low ratio is indicative of the fact that the partitioning of the metabolites are skewed in favour of non-economic product like straw rather than towards grain formation. Consequently, it is considered a poor grain yielding crop (Bommegowda and Krishnamurthy, 1977).

In spite of it, it sustained for thousands of years, if not millenia, as a staple food crop of millions of people in mostly drought-prone areas of Africa and Asia because of its tasty and high energy efficient food compared to other grain-based foods for the people engaged in hard and arduous daily chores. Even with all these virtues, the crop began to lose ground all over in recent years, more severely, especially in Africa. The loss of acreage was so much that led Prof. Katriana Devos of Georgia University to comment in 2005 that “finger millet crop, which was flourishing in millions of hectares, in just about 30 years ago could now be found only in small plots to serve as a prestige fare in some special occasions". It is, Indeed, an unenviable fall in stature!!

India also no better. It too had lost a million hectares out of 2.3 million hectares it had during quincunnium 1950-55. But the good thing about it is that it had maintained the overall production of 2.0 million tonnes, much more than 1.6 million tonnes it had during 1951-55. This was not a miracle. It was, indeed, a function of overwhelming increase in productivity from a mere 700kg/ha to 1471 kg/ha. It is needless to say that it was a reflection on good research being done over these years in addition to pragmatic public policy support services. The crop is in a right mettle now and is poised to recover the lost ground.

Integrated research initiated during 1950s and 1960s under the aegis of an all India Coordinated Small Millets Improvement Project sponsored by the Indian Council of Agricultural Research, New Delhi, had given a good impetus to develop a number of high yielding varieties and corresponding crop production technologies, which have aided and abetted a number of developmental programmes so as to keep the productivity and production levels at a fairly high levels. Similar research and developmental programmes had been undertaken by many finger millet growing countries in Africa too. What is more important now is to intensify agronomic research so as to fully exploit the innate yield potentials of the new and modern varieties in both the continents.

Nearly 90% of the crop is raised under rainfed conditions in India during kharif season (June to October- November) and only a small percentage of the crop is under irrigation during rabi season (post-monsoon period) and summer. In the former, seeds are directly sown either by broadcasting or drilling with the aid of multi-tined wooden seed drill, whereas in the latter the seedlings are raised in the nursery beds and then transplanted. Decidedly, the yields of transplanted crop are much higher than the direct-sown rainfed crop. Under dryland conditions to get better yields, preparation of the seed bed becomes a prerequisite. It is variable according to the regions as well as seasons.

Lesli C. Coleman (1920), a pioneer in ragi research and development in Karnataka, India advocated fallow cultivation. But the soils being laterite-originated red-sandy loams and shallow, their water holding capacity has been very low. And also the surface soil became very hard after the cessation of monsoon rains and not so easy to penetrate through with indigenous implements. Thus this practice did not progress much. Nevertheless, Tanzania (Africa) favoured this system of cultivation as, according to Msuya(2003), in fallow cultivation seed germination was good and seedlings emerged and grew well. Application of wood ash, either from burning the weeds or from the slash and burn system of natural woods or grass lands improved soil fertility. Moreover, it also optimised the use of scarce labour force during the peak season of ragi cultivation. This system appears to be akin to **"shifting or zoom cultivation"** widely followed at one time by the tribal farmers living in hilly regions of North-Eastern and sub-Himalayan regions and other hilly tracts in Central India. However, this system has almost faded out now with the advent of settled farming and improved terraced cultivation of slopy lands in the hilly region.

Jhoney Monithottan and Francis (2007) reported that Muthuvan tribes in Idukki district of Kerala, down in south India, adopted slash and burn method of cultivation of ragi. Selection of land was based on certain ecological factors such as the presence of certain vegetation/ trees like *Carex mysurus* and *Scleria terristris*. Their intercropping pattern, seed material storage and cultivation method (shifting cultivation) had remained unique in several ways. *Katty* has been a special dish prepared by these people from ragi for their consumption.

In the plains of India, farmers start cultivation of land as soon as the monsoon rains start from June onwards depending on the rainfall pattern. The land is ploughed 2-3 times by a wooden plough fitted with an iron or steel share. The types of ploughs used in different regions slightly vary in their size and shape. Depth of ploughing in red sandy-loams of Bangalore plays an important part because there was no response beyond 12-15cm; but could vary in different types of soil in ragi growing areas (Jawaregowda and Krishnamurthy, (1977). Since most of the soils were of lateritic origin, they became hard and formed crust, which came in the way of water infiltration. For conservation of soil moisture, tillage every year was found essential (Lingegowda *et al*., 1986). To improve quality of tillage, an improved iron plough called Kolar Mouldboard plough was introduced. It not only penetrated slightly deeper but also turned the soil over such that the deeper soil could be exposed to weathering processes and destroy hibernating insect pests and weed seeds, if any. It also broke the hard soil pan formed underneath because of repeated ploughing with indigenous wooden plough upto a certain depth. This also helped infiltration of rain water and conserving it for longer period.

The preparatory cultivation, generally, followed by the farmers, was ploughing once or twice with the iron mould board plough followed by multi-tined wooden harrow twice before sowing. Varieties GPU.26, VL.149, PR.202 and Indaf.8 were sown with fortnightly intervals during June and July months in Dharwad region of Karnataka. The June sowings produced highest yield of 3.21 t/ha and decreased in later sowings (Ashoka and Halikat, 1977). The present situation is that new varieties from Indaf and other series could be conviently sown right upto end of August without any perceptible loss in yields, and may even spill over to first week of September with a risk of small yield loss.

Method of Sowing

Finger millet in India is usually sown by broadcasting and covered by passing the brush harrow twice once along the field and another across the field. No doubt that the seed rate used was very high so as to compensate for the risk of losing seeds from germination and consequent patchy crop in the field. In this method, there is no control over the number of plants per unit area and spacing between the plants. Many a time, it ends up in overcrowding. This would be rectified by passing a small 4 tined wooden harrow, commonly called *Chippukunte* twice to thin out the seedlings. It could also be done at the time of manual weeding later, which is the usual practice.

However, the best method of seeding would be by drilling with a multi-tined wooden seed drill. This enables the sowing of measured quantities of seed, sowing in rows and placement of seed uniformally at a particular depth. So it is a better method than broadcasting. Since it involves more labour and cost, this method often becomes scarcer.

Mechanical seed drills are, of late, becoming preferred devices to sow the seed. Senapathi *et al.* (1992) tested five seed drills over three rainy seasons. The results were that calculated overall performance indices based on the weightage given to various parameters and the ratings assigned to these measured values indicated that the Gujarat State Fertilizer Corporation seed-cum-fertilizer drill was by far the best in the lateritic soils of Odisha state in India.

Kumar and Gowda (2005) evaluated a modified tractor drawn cotton planter for drilling ragi and compared its performance with the indigenous wooden seed drilling. It was tried in red sandy soils of Bangalore during kharif season of 1991. The results were that the tractor-drawn mechanically metered planter covered an area of 0.6 ha/hour and dropped seeds at a depth of 2.5 to 3.0 cm. Field efficiency of the former was 85% as against 90% of the latter. But seeding with planter was more precise in dropping and placement of seeds and the operation was faster too. Soil moisture retention and feeding the plants at flowering, grain filling and harvesting stages were at higher ranges, plant growth parameters and yields were higher. Further, drilling with mechanical device was more advantageous than the indigenous drilling method in terms of timesaving spacing regulation and plant density. Conservation of soil moisture, plant growth and finally yield of grain were also better.

But the lacuna is the small farm holder in India is not quite geared up to switch over to new system due to cost-ineffectiveness *vis a vis* his farm holdings. In otherwords, it is a matter of shear economics.

Direct seeding vs transplanting

Comparatively speaking, transplanting is much better than direct sowing of seed. Sambasivarao and Raghavalu (1964) demonstrated that out of 4 varieties, variety *Purna* gave a better yield of 4.5 t/ha of grain than 3.6t/ha by direct sowing at Anakapalle in Andrapradesh. Higher yield was accounted for by the cumulative length of fingers in the earhead, grain densities, weight of the grains per ear and so on in the transplanted crop.

Kasajma *et al*. (2008) at Shinshu University, Japan compared three Japanese varieties with 6 Nepalese varieties for their response. The crop was not fertilized. While direct sowing of Nepalese varieties yielded significantly more than the Japanese varieties, the Japanese varieties were not. Comparative conditions in the first principal component analysis revealed that either the ear weight or the number of ears or type of the ear were responsible for differences in yields. The second principal component analysis was considered to be the factor related to the yielding ability and tillering activity. The number of grains per ear was significantly greater in direct sown Nepalese varieties than in transplanted plants. Transplanting tended to give lower number of tillers and ear number, which contributed to their lower yield. But the Japanese varieties were hardly affected by transplanting. However, a change of plant type from ear weight to ear number was also found with transplanting. On the whole, Nepalese varieties in Japan did better under direct-sowing than transplanting compared to Japanese varieties.

At Anakapalle, Andhrapradesh, Rao *et al.* (1981) found that two varieties planted in the beginning of August or beginning of September during 1984 to 1986 (3years) resulted in the grain yields of 2.52, 2.42 and 2.0t/ha, respectively. With regard to plant density, 2,96,00, 4,44,000 or 5,93,000 plants/ha yielded 2.48, 2.41 and 2.11 t/ha, respectively. High yields in early planted crops were associated with low plant density, while in the late-sown crop, it was the other way round. Varieties JNR.1000 and JNR.842 planted with 2,60,000, 3,30,000 and 4,40,000 plants/ha combined with the application of 0,40 and 80 kg N/ha recorded the highest yield at 2,60,000 plants /ha combined with 80kg N/ha application. But there were no differences between varieties at any of the plant densities and N dosages (Khan and Agarwal, 1993).

In transplanted crop, age of the seedlings at planting assumed importance. At Ranchi (Bihar) in 1985-87, 21-day old seedlings of the variety A.404 were planted in sandy loam soils on 25th June at an inter-row spacings of 20, 30 or 40 cm resulted in the yields of 2.73, 2.57 and 2.57 t/ha, respectively. Even at the spacings of 10,15 or 20 cm row spacing the yields were 2.52, 2.67 and 2.68 t/ha, respectively. When the seedlings were planted on 15th July, the corsesponding grain yields from delayed establishment in the nursery and transplanting on July 15 were 2.29, 2.11, 1.90, 2.30, 2.10 and 1.92 t/ha, respecively. From this trial, it was evident that the right age of seedlings for transplanting could be 20 to 25 days from sowing in the nursery bed. However, Divakaran (1967) reported that 20 days old seedlings were the best for getting good yields.

In a trial at Bangalore, a dwarf and short duration variety Indaf.8 was sown late along with inter-crops of pigeonpea and field bean (*Lablab purpureus)* in the ratio of 3:1, 6:2 or 5:2 row spacing, yield of finger millet was higher in cv. Indaf.8 (1.37 vs 1.25 t/ha) but was not significantly different between inter-crops with two legumes. Yield was slightly lower in the 5:2 inter-cropping ratio (Shivakumar and Yadehalli, 1996).

Ramshe *et al.* (2002) studied during kharif season from 1991-92 through, 1996-97 the effect of different dates of sowing and methods on yield under rainfed condition in Kolhapur region of Maharashtra, India. There were 8 sowing methods at different meteorological weeks, viz., dribbling during meteorological week (MW) 22, drilling during 22 (MW), dribbling during (MW) 24, broadcasting during (MW) 24, and transplanting during (MWs) 27 to 29. The six years poolled data revealed that the maximum grain yield of 3.7 t/ha was obtained from drilling the crop during (MW) 23 (4-10 June). Maximum straw yield of 10t/ha was obtained from drilling the crop during (MW) 22. Broadcasting and transplanting methods recorded the lowest grain and straw yields. However, the best yields were from dribbling from (MWs) 22 to 24.

Method of planting and spacing

Effect of methods of planting on growth and yield was studied in sandy-loam soils at Bangalore during kharif, 2006 by Kalaraju *et al*.(2009). There were 12 treatment combinations, viz, three varieties, two planting methods such as line sowing with a spacing of 22.5 x 10.0 cm and square planting/Nethi ragi 30 x 30 cm spacing and two levels of application of farm yard manure (10.0 and 12.5 t FYM). Results were that the variety GPU.28 produced an average of 20 tillers per plant, 8.6 fingers/earhead, 9.0 cm earhead length, 112.33 g/plant of dry matter accumulation and the grain yield of 3.52 t/ha. These results were significantly higher with the application of the same amount of FYM under a similar system of planting produced the higher straw yield of 6.0 t/ha with a medium grain yield of 3.1 t/ha.

Reddy and Havanagi (1992) studied the effect of system of planting finger millet-pigeonpea combination during Kharif season of 1981-82 at Bangalore. The varieties PR-202 of finger millet and HY.3 of pigeonpea were sown alone or in combination in a single row or paired rows, either both of them were sown simultaneously or finger millet was transplanted 45 days after sowing pigeonpea. Grain yield of finger millet was 2.6-3.5 t/ha when grown alone and 1.5-1.7 t/ha when the crops were raised combinedly. Transplanting of finger millet 45 days after sowing of pigeonpea increased the yields of both the crops. However, sowing of pigeonpea in paired rows increased the yields of finger millet. Planting two rows of finger millet in 60/90 cm paired rows of pigeopea gave the highest staple land equivalent ratio (Reddy and Havanagi, 1992).

In West Bengal, India the spacing at 25 x 10 cm resulted in significantly higher dry matter accumulation, leaf area index, crop growth rate, number of earheads/m^2, number of fingers per ear and 1000 grain weight. The grain yield was higher by 28.7 and 20.3% with the wider spacing of 25 x 10 cm with 4,00,000 plant population/ha over medium or closer spacing of 25.8 cm and 25 x 6 cm, respectively. Grain and staw yields increased with the increase in nitrogen and phosphorus levels at N + P at 60 kg/ha each, followed by 60kg N + 30 kg P/ha, and 60 kg N/ha (Roy *et al*., 2002).

Management of nursery bed for raising seedlings

Indeed, transplanting is a better method of finger millet production than direct sowing as it gives higher yields of grain and straw besides facilitating post-planting operations. Prerequisite is to raise the healthy and strong seedlings in the nursery and management occupy an important position.

Nursery area is well prepared by ploughing twice or thrice, forty seed beds of 25 x 4 size should be prepared with friable soil. Three baskets full of FYM, ½ kg of ammonium sulphate, one kg of superphosphate and ½ kg of muriate of potash were applied per bed and incorporated into the soil well. Seeds were sown at the rate of 60g/bed, which amounted to 5 to 6 kg/ha. Beds were watered regularly as and when needed. Seed rate above this at 40 g / bed or 80-100 g / bed affected the quality of seedlings by way of lean and lanky growth of seedlings devoid of proper root growth and vigour of seedlings. Besides, the seedlings had longer internodes with reduced number of leaves. Such seedlings had a difficulty to establish well and give a normal crop in the transplanted field and gave significantly reduced yields (Sambasiva Rao and Raghavalu, 1964; Rajasekhar *et al*., 1971).

Seed hardening / presowing treatment of seed

Seeds were precsoaked in pure water overnight and shade-dried to reduce the moisture to 50% prior to sowing. Treated seeds germinated earlier and shown better growth and vigour (Dawson, 1966). Further, pre-soaked or seed hardening responded better to the application of fertilizer, grew faster with well developed root growth and preformed well under soil moisture stress (drought) during growing stage. Root length and plant vigour had increased ranging from 0.3-42% (Sastry *et al*., 1969; Rajasekhar *et al*., 1970).

Maitra *et al*. (1999) observed that pre-sowing treatment of seeds of five varieties with 100ppm Na_2HP0_4, 100ppm KH_2P0_4, 0.25% $CaCl_2$

and water improved grain yields by 55,47 33 and 21%, respectively. Grain protein content was highest in cv. A.494, but was not affected significantly by seed treatment.

Cropping systems

Mixed cropping: In Karnataka (India) farmers invariably follow mixed cropping system by sowing a row of field bean (*Lablab purpureus*) after every 4 to 6 rows of ragi , fodder sorghum, a smattering of castor or niger under rainfed condition. The objective behind this system was to grow something of everything that the farmers household required for their family consumption. Ragi would mature earlier than other crops and harvested. Field bean, which is usually an indeterminate type produced numerous vines in the initial stages, which the farmers harvested for fodder and allow the field bean to grow, flower and form pods. Green pods at the early stages are used as vegetable and when it matures and dries, seeds are separated from the pods and use as pulses (source of protein). Fodder sorghum, which is faster in growth than ragi, is cut and fed to cattle as green fodder. The other crops, which are minor in scale, are harvested at different times and used for home consumption.

The basic principale involved in the mixed cropping system is, apart from getting some thing of every thing for domestic use, it also acts as an insurance against the total failure of ragi crop due to unforeseen causes such as severe drought or disease outbreak and so on. It is, in a small way, acts as a compensatory mechanism.

Krishnamurthy *et al*. (1969) demonstrated that inter-row space in the sugarcane crop, which is rather wider, was utilized for growing ragi as an additional crop by applying additional quantity of urea to the extent of 125 kg.ha area. Of course, it was under irrigated condition since suagrcane is generally an irrigated crop. A total of 160 kg/ha of yield of ragi was obtained by this system, which was indeed a bonus crop without in any way affecting sugarcane crop.

Double cropping / relay cropping under rainfed cultivation

Javaregowda and Krishnamurthy (1997) reported that as soon as the South-West monsoon breaks out, cowpea or soybean was sown and harvested well before the time for ragi sowing and then a regular crop of ragi was taken. This had benefitted the farmer better than a single crop of ragi during kharif season (Anon., 1975). This system is possible if the early rains in June are favourable for taking the other crops and that they should mature and vacate the field to accommodate ragi crop almost by the end of August, which is the upper perimeter for sowing the latter.

Hebbar *et al*. (1997) tried such a double cropping or a relay cropping system involving ragi after cowpea (for green manure and fodder) or niger, sesame or horsegram or soybean as preceding crop in July 1988. Grain yields of ragi were 2.34, 3.14, 0.15, 0.18 2.47, 0.94 and 2.83t/ha, respectively, compared with 0.2t/ha from an August established crop of ragi after fallow. Low grain yields of ragi following niger, sesame and soyabean were largely related to moisture stress during the grand growth period of the ragi crop. Grain yields from crops established by transplanting were greater than from directsown crop (1.81 vs, 1.2 t/ha).

The influence of improved management and variety on yields of upland rice and ragi under rainfed condition in Jharkand (India) in 1985-87 was studied. The variety of rice sown was *Browngorai 23-19* and A.404 of ragi. The crop was fertilized with 40 kg N+30kg P_20_5 + 20 kg K_2O/ha and protected against pest damage 25-30 days after sowing. This was compared with the farmer's method of management in which 125-150kg/ha of rice seed was broadcast. Only 4 t FYM/ha was applied and no other fertilizers were used. Weeding was delayed upto 35-40 days after sowing with no plant protection treatment. Results were that under improved crop management practices the highest yields of 1.95 t/ha and 2.02 t/ha of rice and ragi were obtained, respectively as against 1.72 and 1.82 t/ha, respectively, under farmers practice. This emphasised the fact that improved management practices were important to get better yields even with the local cultivars (Singh *et al*. (1989).

From an experiment conducted by Vedprakash *et al.* (2005) in Uttarkhand of India during the winter seasons of 1996-97 and 1998-99 evaluated the grain yields of wheat and finger millet under relay cropping systems: Sole finger millet; wheat, finger millet (drilled) + pigeonpea at 8:2 row space with, wheat. Pooled data showed that the yield of finger millet was lower under all the intercropping combinations than under sole cropping. However, the yield reduction of 12.8% was the lowest with finger millet (transplanted) + pigeonpea at 4:1 ratio. The finger millet equivalent yield was higher under intercropping (6.49-6.56 t/ha) than under sole cropping (3.37 t/ha). Wheat yields were significantly affected by the preceding cropping system except in the third year, when yield variations were not significant. The highest mean wheat grain yields were recorded when wheat was grown after finger millet (transplanted) + pigeonpea at 4:1 ratio), finger millet (drilled) + pigeon pea at 4:1 ratio and sole finger millet. The relay cropping of wheat in finger millet + pigeon pea combination increased the gross and net returns by 15.9-30.1 and 69.82-139.5%, respectively, over finger millet-wheat cropping sequence. Relay cropping of wheat in finger millet (transplanted) + pegeon pea at 4:1 ratio registred the highest gross and net returns and benefit-cost ratio of 1.65. This treatment also resulted in the greatest production efficiency in a calendar year of 29.9 kg/ha / day.

Performance of double cropping/relay cropping system comprising cowpea and cluster bean for fodder or for incorporating into the soil as green manure after picking the green pods for use as vegetables and each of them followed by finger millet under rainfed condition was studied by Padhi *et al*, (2010) in Odisha, India. Among the double-cropping system, cowpea as green manure-finger millet combination recorded the highest finger millet grain equivalent yield (FMGEY) of 4.95 t/ha, land-use efficiency of 61%, production efficiency of 22kg/day/ha, B:C ratio of 1.79 and energy-use efficiency for economic produce of 321g/MJ. Both the crops in this sequence performed better. Application of P followed by transplanting finger millet gave a significantly maximum finger millet grain yield of 2.20 and 2.25 t/ha, respectively; FMGEY of 4.46 t/ha and 4.5 t/ha and cost-benefit ratio of 1.88 and 1.82, respectively. It also gave energy-use efficiency for economics of 316 and 31 g/MJ and biological produce of 620 and 623g/ MJ. In cowpea-fingermillet system, application of P and transplanting of finger millet recorded the highest uptake of residual soil nutrient content.

Sequence cropping system under irrigation at Bangalore revealed that ragi in kharif , onion in rabi, potato in rabi and again ragi in summer were found to be very remunerative crop sequences under Bangalore conditions (Lingegowda *et al*., 1986). Finger millet was grown in the North-West Himalayan region in India during 1982-84 rainy seasons following wheat, peas or lentils, or wheat-legume intercrops in winter season. Finger millet was given 0,20 or 40 kg N/ha. Mean yields of grain were 1.56, 2.07 and 2.41 t/ha respectively (Prakash *et al*., 1991). Mean yield of 1.75 t/ha after wheat and 1.98-2.19 t/ha after peas or lentils in pure stands or intercropped with wheat-legumes increased available soil N, while organic carbon concentration was highest after wheat-legume intercrops.

A study of different cropping systems and fertilizer application rates on the growth, yield and nutrient up-take by finger millet (cv.GPU.28) at Bangalore revealed that intercropping of finger millet with pigeon-pea in 8:2 row ratio recorded significantly higher growth and other yield parameters. It also showed higher N (133.8 kg/ha), P_2O_5 (27.5kg/ha) and K_2O (87.4 kg/ha) uptake. Application of recommended fertilizer rates at 50:40:25 kg NPK/ha together with 5 tonnes of compost per hactare showed significantly superior yield parameters and NPK uptake of 115.3:34:77.3 kg/ha (Umesh *et al*., 2006).

A genotypic compatibility study was made by Parida *et al*. (1989) in intercropping systems involving three varieties each of pigeon pea and finger millet in solo and intercropping combinations under dryland condition at Bhubaneshwar, Odisha, India for three years. Results revealed maximum seed yield of 0.6 t/ha and high-land-equivalent-ratio of 1.57 when intercropped with medium duration finger millet variety, PR.717.This system had minimum crop competition, best crop compatibility, highest grain productivity of 1.60 t/ha of finger millet and high monitory returns.

Intercropping systems

Rice variety *Heera*, finger millet var. *Neelanchal,* soybean var. *Gaurav* and rice bean *(Vigna umbellulata)* var. SRBS.43 were studied either alone or intercropped with finger millet during 1992-94 in Odisha (Indai). The row ratios maintained were 5:2 or 3:2. Finger millet soybean in 3:2 ratio produced the grain yields of 1064 and 961 kg/ha, respectively, and the highest rice equivalent yield was 3341 kg/ha (Mahopatra and Halder, 1998). Spraying pigeon-pea at flower bud initiation to pod formation or pod formation to pod maturity produced significantly better yields than without insect pest control and was more cost-effective than spraying insecticide at other stages.

Intercropping of finger millet in combination with groundnut was studied by Runkulatile *et al*. (1998) in Japan for establishing the advantages of intercrop combinations, ratios, soil moisture status and nitrogen availability. Three intercrop systems in 1:2, 1:1 ans 2:1 ratio in alternate rows of groundnut were examined for their growth and yield in comparison with solo cropping system during 1966. The effect of adequately watered (W) and water-stressed (D) conditions on the intercropping adavantage was also examined for 1:1 intercrops in 1995 and 1996. Fertilizer N was applied at the rate of 20kg/ha in 1995 and 50 kg in 1996. The total above ground biomass (DM) and its land-equivalent ratio (LER) were highest in the 1:1 combination ratio. The DM production of intercropped finger millet was higher in 1996 with higher N than in 1995 with low N application, while that of groundnut was similar in both years. Intercropped groundnut exhibited significantly higher DM production after the harvest of finger millet.

The LERs in garin yield were higher in 1996 (1.43 under W and 1.45 under D), than in 1995 (1.87 under W and 1.22 under D). LERS were consistently higher under D than under W conditions. Water stress severely reduced the leaf area index (LAI) of finger millet at the lower N rate, especially in the later stages, whereas higher N status alleviated the water stress effect. A close linear relationship was observed between LAI and leaf area (LA) per unit leaf N both for groundnut and finger millet with intercrops producing larger LA per unit leaf N than single crops. Intercropping maintained higher ability in leaf net photosynthesis and transpiration of groundnut upto the later stages and significantly reduced water evaporation from the soil surface under canopy compared to solo finger millet cropping.

Intercropping of ragi with various legumes in West Bengal, India during 1994-95, sole groundnut had given higher dry matter yield, leaf area index and crop growth rate at early stages. However, sole groundnut, finger millet, pigeon-pea and finger millet + groundnut intercropping recorded higher values in respect of all the attributes cited earlier at later stages. Sole finger millet produced more ears/m2, but finger millet + pigeonpea intercropping recorded higher number of fingers than the other cropping systems. Finger millet + groundnut, finger millet + pigeon pea and sole finger millet gave higher yields than the other cropping systems. Application of NPK at 60:30 kg/ha recorded the greatest dry matter yield, leaf area index and crop growth rate. Fertilizer treatment also increased the number of fingers per plant, pods per plant, seeds and kernels per pod compared to that with the lower fertilizer levels. Further, yields of all the crops increased under sole and intercropping systems at higher levels of fertilizer application (Maitra *et al*., 2001).

Intercropping of finger millet with pigeon-pea, transplanting of finger millet 45 days after sowing of pigeon-pea to determine the pattern of uptake of N and P by both the crops was done at Bangalore during 1981-82 by Reddy and Havanagi (1991). N and P uptake by both the crops was higher when finger millet was transplanted than when both the crops were sown on the same day. However, nutrient uptake was higher with pigeon-pea when it was sown alone in single rows than in paired rows in the proportion of 1:3 rows of finger millet between the paired rows. Intercrops had higher nutrient requirement than their respective pure stands.

Ramamurthy *et al*. (2003b) studied the influence of field bean (*Phaseolus vulgaris)* on the growth and development of finger millet varieties CO.11 and CO.13. Study also included the impact of clipping vegetative branches of field bean on the productivity of intercrops. The highest grain and straw yields were observed with the sole finger millet variety CO.11. When CO.11 variety of finger millet was grown with indeterminate type of field bean and vegetative branches of the latter clipped, higher garin and straw yields of both finger millet and field bean land equivalent ratio were obtained. Similar results were also obtained in the intercrop combination of finger millet var. CO.11 and pigeon-pea.

Intercropping of rgai with soybean in sandy-loam soils of Bangalore was tried during 1986 by Devi *et al*. (1990). Soybean was grown alone at normal spacing of 30 x 10 cm and the recommended dose of fertilizer (25 N: 37.5 P_2O_5 20 K_2O kg/ha) was applied. Finger millet was grown alone with recommended rates of fertilizers in rows at 22.5 or 40 cm apart and both were intercropped with 0, 50 or 100% recommended dose of fertilizers, in which finger millet was sown in rows at 45 cm apart. Finger millet in this treatment resulted in highest grain yield of 3.67 t/ha, LER of 1.71 and also gross returns. Finger millet in pure stand at 45 cm spacing gave a grain yield of 3.06 t/ha. Whereas soybean yielded 0.62 t/ha in pure stands and an average of 0.26t/ha when intercropped.

Effect of row arrangement on yield and yield advantages in sorghum-finger millet intercrop combination was studied at Kampala in Uganda by Swkabembe (1991). Treatments included pure sorghum var. SB.65, pure finger millet var. Serese and sorghum + finger millet mixture in ratios of 3:2, 2:2, 1:2, 1:4 and 1:6 rows. Four plant population densities were maintained for each treatment with-in row spacing for both the crops approximately 7.5, 15.0, 22.5 and 30.0 cm. A linear relationship was found between the yield and plant density. However, intercropping sorghum with the increasing proportion of finger millet rows reduced the grain yield. Differences in land-equivalent ratios between row arrangements were not significant although 1:2 sorghum-finger millet row arrangement gave 20% yield advantage.

Inter-cropping of finger millet varieties PR.202, Indaf-1 and local Kaddimurka with *Vicia faba* or lucern cv. PV at Bangalore during kharif 1978 in sandy-loam soils, finger millet cv. PR. 202 gave the highest yield of 4.33 t/ha, but it yielded 3.13, 3.99 and 3.06 t/ha when grown alone and intercropped with field bean and lucern, respectively. The highest land-equivalent ratio of 1.1 was obtained when cv. Indaf.1 was intercropped with lucern (Shankarlingappa and Rajshekara, 1992).

Inorder to elicit the impact of field bean *Phaseolus vulgaris* on the growth and development of ragi, var. CO.11 and CO.13 also of clipping of vegetative branches of field bean on the productivity of intercrops, a trial was undertaken by Ramamurthy *et al*. (2003). The highest grain and straw yields of both finger millet and field bean and higher garin-equivalent yield, land-equivalent ratios were obtained. Similar intercropping with pigeon-pea var. VCN.1 with finger millet variety CO.11 yielded higher grain and straw yields relative to other intercropping systems. Land-equivalent ratio and cost-benefit equation was also highest.

Pigeon-pea cv. CO.5, grain cowpea cv. Co.2, green gram cv. Pusa bold and vegetable cowpea cv. CO.2 were intercropped with finger millet cv. CO.13 in the ratio 8:2 at Coimbatore during rabi season of 2001. The greatest plant height of 107 cm, dry matter production, number of productive tillers per plant (8.8) and grain yields of 2141 kg/ha were obtained with finger millet in the vegetable cowpea combination. With regard to pulse crop, strip cropping with pigeon-pea resulted in greatest plant height and number of pods per plant were obtained with green gram. However, the highest yield of finger millet combined with pulses was recorded in strip cropping with vegetable cowpea (Ramamurthy *et al*., 2003).

A study involving the effect of intercropping finger millet with two indigenous legumes at different nitrogen levels at Kabete and Njora in Kenya was made by Akuja *et al*. (2003). The study was done at two phases. The first phase involed an indigenous edible legume *Crotalaria brevidens* and a fodder legume *Trifolium quartinianum* in an intercrop combination with finger millet. Crop was fertilized with nitrogen at 0,20 or 40 kg N/ha in the form of urea (46% N). Two methods of harvesting (uproot and cut and carry) were followed at the end of phase-1. In the phase-2, a pure stand of finger millet was sown to findout the effect of residual nitrogen in the soil. The results indicated that residual nitrogen had a positive significant effect ($P<0.05$) on the fresh and dry leaf weights of *Crotalaria brevidens* at both Kebete and Njora sites.There were also significant CP <0.05 differences caused by applied nitrogen rates on leaf fresh and dry weights of *Trifolium quartinianum* at both the sites. The study, however, revealed that inter cropping favored growth of *C.brevidens* but not *T.quertinianum.In* addition, there was a depression in the growth and yield of finger millet. However, the latter was a better legume in legume-based intercropping of finger miller.

Intercropping of ragi var.A.404 with black gram (*Phselous mungo*) var.T.9 with upland rice var. *Kalinga* during 1989-90 at Hazaribagh in Bihar revealed that in 2:1 or 3:1 interrow ratios, grain yield of rice was 2.8 t/ha when grown alone and 1.5 t/ha-1.88 t/ha when sites cropped with finger millet and mung yielded 1.78 and 0.44 t/ ha,respectively, when grown alone. When intercropped, it was 0.71,1.41 and 0.16-0.71 t/ha,respectively. The highest plant equivalent ratio of 1.45 was obtained when rice and finger millet were intercropped in 2:2 ratio (Singh *et al.,* 1992).

In kharif 1987-78, a variety of chilli (red pepper) *Pusa jwala* was grown alone at Bangalore with aspacing of 40 x 45 or 60 x 30 cm and intercropped with finger millet, which was grown either alone or at a spacing of 30 x 10 cm.When both the crops were intercropped with or without irrigation,grain yield of finger millet was 3.5 t/ha when grown alone and 2.98 t/ha when intercropped. Green chilli yield was 8.21 and 8.34 t/ha when grown alone at a spacing of 40 x 45 and 60 x 30 cm spacing, respectively, compared with 0.79 t/ha when intercropped yield of both the crops under protective irrigation (Rammurthy *et al*. 1993).

Fertilizer managment

Earlier, application of inorganic fertilizer to ragi crop was a novelty under dry land condition. But it has now become a common routine with the adoption of modern varieties with dwarf stature, short duration and high response to fertilizer application. Nevertheless, the degree of response depends upon the variety, soil type, rainfall pattern, type of fertilizer, method of application, economic returns and so on.

Krishnamurthy (1970) observed the differential levels of response to nitrogenous fertilizers as measured by the grain yields and 80 kg/ha was reported to be optimum for all the varieties involved in the study both during Kharif and summer seasons at Bangalore. However, it was found that some varieties responded even upto 100-101 kg/ha (Krishnamurthy, 1971). But Rajasekhar *et al*. (1974) and Lingegowda *et al*. (1974) found linear response upto 80kg N/ha and it was economical, beyond which the response tapered out. Soils at Bangalore being red sandy-loams and are slightly acedic, they responded better to calcium ammonium nitrate (CAN) than to other sources of nitrogen (Ananthanarayana *et al*. (1971). Chinnaswamy *et al*. (1976) observed that application of CAN at the rate of 45kg N/ha in the presence of 22.4 kg P_2O_5 + 22.4 kg K_2O/ha over a basal dose of 12.5 t/ha of Farm yard manure gave the highest grain yield of 3.73 t/ha. Method of application of these fertilizers also played an important role. Yadav and Srivatsava (1972) reported that instead of applying entire recommended quantity of nitrogen all at once, splitting it into two doses, ½ at planting and the rest as top dressing, elicited better response. Even the density of plant population in an unit area (spacing) had a role in determining the level of response to applied nutrients. Highest grain yield was obtained with 22.5 x 15.0 cm spacing upto the N level of 101 kg N/ha. But it was found that even 67 kg N/ha was enough if 45 kg P_2O_5 was combined with it. However, response of the crop to the application of potassium (K_2O) was erratic (Rajasekhara *et al.,* 1971).

Tandon (1971) found the response of the variety *Purna* to N application at Bangalore and Mandya under irrigation. Grain yield was 2.1 t/ ha at the level of 102 kg N /ha, which amounted to 20.5 kg of grain yield per kg of N applied. However, Thirupathi and Morochan (1973) observed that it was only 18.06 kg of grain per kg of added nitrogen even upto 50kg N/ha and yields progressively decreased with the incremental doses of nitrogen beyond that. Response to N application was variety-specific was reported, either it was linear or quadratic. Nevertheless, N among major nutrients becomes critical.

Role of Phosphatic Fertilizers

Hegde *et al*. (1972) emphasised the essentiality of P and K for the uptake of N by the plant and that in their absence plant growth was not normal leading to depressed yields. On the other hand, if P is infused, plant growth was more vigorous irrespective of the status of K. It was proved that, when N and K were applied, the yield was only 0.7 t/ha as against 1.64 t/ha when it was supplemented by 25 kg P_2O_5. This clearly indicated that application of 50 kg P_2O_5/ha in addition to normal doses of N and K were essential for maximizing grain yields.

Kempanna *et al*. (1968) and Kempanna (1975) tried the effect of P on two varieties, viz., HES. 927 (a new selection from African collections, now rechristened as IE. 927) and local variety *Purna* at Bangalore. Individual plot size in the experiment was one square meter, bound on all sides by bottomless square cement cisterns, which were embedded in the soil to a depth of 30 cm. These cement cisterns while simulating natural conditions precluded the lateral movement of soil moisture and plant nutrients besides preventing likely inter plot interactions. Five levels of P_2O_5 at the rate of 0,16,32 on 64,128 kg/ha were applied to each cistern proportionately. *Crotalaria juncea* (a legume green manure crop) was grown in each of the cisterns and the entire quantity of phosphatic fertilizer at the rate already indicated was applied to the green manure crop when it was 5 weeks old; the green matter was chapped and applied to these microplots at the rate of 1 kg/ cistern. In addition, an uniform dose of nitrogen at the rate of 32 kg N/ha in the form of ammonium sulphate was applied in split doses. The sources of Pand K, which were applied to the previous green manure crop, were superphosphate and muriate of potash. Twenty one day old nursery-raised seedlings were transplanted and plots were regularly watered. A uniform dose of 32 kg N/ha was applied proportionately to each of the cisterns in the form of ammonium sulphate. The treatments were replicated thrice.

Results indicated that both the varieties responded, but differentially. However HES.927 (now IE-927) was superior to *Purna* in its response to P. Varieties responded to all the levels of P. Yield increase was linear upto the level of 128 kg P_2O_5/ha even at the level of just about 32 kg N/ha. Variety *Purna* lagged behind and difference in yield between the two was 12%. The point to note here is that there is greater scope for broadening the yield responses to fertilizer application provided they are optimally balanced.

Rainfed finger millet trials in lateritic soils during kharif 1988-90 at Kolhapur, Maharashtra indicated that varieties, Dapoli.1 and B.11 applied with 0,30 or 60 kg N/ha and 0,10 or 20 kg P_2O_5 gave a grain yieeld of 2.9 t/ha and 3.1 t/ha, respectively. The difference between the two sets of results was due to the addition of 20 kg P_2O_5. Grain yields increased upto 30 kg N/ha (2.9 t/ha) and was the highest at 3.1 t/ha when P_2O_5 was included in the fertilizer schedule. The varieties Dapoli.1 and B.11 gave the yields of 2.8 and 2.7 t/ha, respectively (Bhosale *et al*. 1994).

Effect of different phosphatic fertilizers on the inorganic phosphorus fraction of a Typic Ustochrept was investigated at Coimbatore by Shigram and Kothandaraman (1992). The residual and cumulative effect of five different sources of P (single superphosphate, rock phosphate+ single superphosphate + phospobacterium and diammonium phosphate) at 13,26 or 39 kg/ha was studied in maize grown after finger millet crop. All the treatments significantly increased the status of inorganic fractions (saloid P, alluminium P, iron P, reductant-soluble P and calcium P) compared with the control. Diammonium phosphate and single superphosphate at 30 kg P/ha increased the accumalation of saloid P and alluminium P compared with rock phosphate and its combinations. There was no significant difference among P sources and levels with the status of iron P and reductant-soluble P. Rockphosphate and its combinations accounted for higher calcium P relative to DAP and superphosphate.

The effect of Lalitpur rockphosphate and superphosphate applied in mixtures in the ratio of 1:1, 1:2 and 2:1 to the finger millet variety VL.124/ wheat cv. Sonalika and barnyard millet (*Echinochloa frumentaceae)* cv. VL.129/ wheat cv. Sonalika rotations were studied on acid Incaptisol soil at Ranichauri, Himalayas during 1984-85. P was applied at sowing of finger millet at 0,30 or 60 kg P_2O_5/ha. The highest grain yields were obtained with 2:1 rockphosphate: superphosphate mixture. The finger millet/wheat rotation yields averaged at 1.58 and 1.82 t/ha, respectively. And the barnyard millet/ wheat rotation yields averaged at 2.21 and 2.09 t/ha. 2:1 ratio of rockphosphate: superphosphate mixture was also superior with regard to p and N uptake by the crops, availability coefficient ratio, P-use efficiency and relative agronomic effectiveness (Dwivedi and Dwivedi, 1992).

Long range experiments were conducted for 8 years from 1964 in permanent series experimental plots under rainfed condition in sandy-loam soils at Bangalore. Variety H_{22} was used for the first 6 years and then changed over to var. *Purna* in the last two years. In the biginning for few years, the crop responded well to the application of 33.6kg N+22.2 kg P/ha and gave higher yields. Subsequently, it became necessary to apply NPK at 67.2N+ 44.4 P_2O_5+44.4kg K/ha to get similar yields or even more than the earlier yields (Nagaraj and Krishnamurthy, 1977). When farm yard manure was applied in combination with N, P and K the addition to P, triggered the yield response (Raniperumal, 1969).

In the pot trial, the effect of applied P_2O_5 from 0-100 kg/ha on the growth and yield of the crop grown on soils collected and used from long term manurial trial plots (1972-1986) with the addition of various NPK rates applied according to soil test values were studied. The highest dry matter yields at different growth satges and grain yield at harvest were with the soil that recived 100% NPK rates + FYM. Yields were further increased with the increase in the rate of P. P uptake was the highest in the 100% NPK+FYM treatment as compared with the lowest uptake in the soils, which were grown without fertilizer application (Anon.,1990).

Okaleba *et al.* (19900 reported that during 1986-87 at Katumani Research Center near Machakos, Kenya *Pennisetum glaucum* cv. Serese 6A and *Eleusine coracana* cv Ekalakala were grown on soils containing 30 ppm P. *E coracana* was given 135 kg P/ha and 40 kg P/ ha as diammonium phosphate (DAP), single superphosphate (SSP) or triple superphosphate (TSP). The SSP and TSP treatments were applied with 120 and 60 kg N/ha to *E coracana and P.glaucum,* respectively (N supplied equivalent to DAP). Fertilizers were either broadcast or banded. P application did not significantly affect *P. glaucum* in comparison to controls. However, banded SSP produced greater grain yields (1.22 t/ha) than the broadcast SSP (0.77 t/ha). But P application increased the yields of *E coracana* (1.50-1.87 t/ha) compared with controls (0.9-1.11 t/ha). In *P.glaucum,* P uptake was the highest with DAP upto the flowering stage. In *E. coracana,* P uptake by grain and straw was similar to all the P fertilizers and their application methods.

In ragi-soybean cropping system with the application of Maton rock-phosphate and acidulated maton rockphosphate at Bangalore, Bhatta *et al.* (1994) found that the best P fertilizer was 25% acidulated Mation rock-phosphate or a 3:1 mixture of rockphosphate and superphosphate.

Method of fertilizer application

Manchegowda (1967) observed that broadcast method of fertilizer application to dryland ragi crop usually followed by the farmers was not an efficient one. The other methods like placement of fertilizers at the rate of 50 kg N+ 25 kg P_2O_5, or 50kg N+20kg P_2O_5 did not show any significant advantage in terms of yields in the first as well as in second year of the crop growth. But the application of 90 kg N/ha had given higher yields (Anon., 1971). However, Ramiaha *et al.* (1970) in their studies at different levels and methods of application of P as band placement found increased yields as compared with broadcasting and plough sole method. It was on par with foliar application. It was also observed that application of 35kg P_2O_5 /ha recorded significantly higher grain and straw yields by 9.8 and 8.8%, respectively, over no phosphate fertilization.

Split application

Effect of level and time of nitrogen application under rainfed condition was studied at Anakapalle, Andhrapradesh during 1984-86. The varieties, VR.550 and PR.1044 were given 0,20,40 or 60 kg N/ha. Fifty percent N was applied as basal dose and 50% at tillering stage; 50% as basal dose+ 25% at tillering+ 25% at panicle initiation stage and equal amounts at basal tillering and panicle initiation stages. Varieties, VR. 550 and PR.1044 produced grain yields of 2.4 and 2.31 t/ha, respectively. However, grain yields increased linearly with N application from 1.71 t/ha without N application to 2.82t/ha with 60 kg N. Split application of N at basal, at tillering and panicle initiatiation stages produced higer grain yields than split application only at basal and tillering. Results from three years pooled data, the optimum N rate was caculated to be 50.2 kg/ha, which produced 2.78 t/ha grain yield.

Application of soil amendments

Biological waste

Influence of biological wastes like maize straw, pig manure, municipal compost, sugarcane bagasse and groundnut husk tried in sandy-loam soils of Tamil Nadu to evaluate the effect on soil physical properties and crop yields of finger millet, var. CO.10 and maize, var. Ganga. In both the cases organic wastes increased the saturated hydraulic conductivity and aggregate stability significantly. Higher grain and straw yields were obtained with pig manure and from compost-treaed plots relative to controls (Mathan,2001)

Vermicompost

From the application of vermicompost on ragi-tomato cropping system at Bhubaneshwar by Senapathi *et al.* (2007), it was found that in combination with 50% recommended fertilizer rate and FYM resulted in the increased height of the plant (17.3 cm), biomass yield (12.73 t/ha), grain yield (2.5 t/ha) and harvest index (16.4) in respect of ragi. FYM and vermicompost had favourable residual effect on the yield of succeeding tomato crop with the total fruit yield of 29.0 t/ha. The combined effect of organic and inorganic fertilizers enhanced the nutrient status of the soil after harvesting. The concentrations of organic C and available N , P and K were 0.41-0.63%, 158-185.5 kg/ha (low), 15.5-21.5 kg/ha (medium) and 136.5-173.5 kg/ha (medium), respectively.

Water hyacinth

Kumar *et al.* (2000) reported from Bangalore the effect of seed inoculation of *Enterobacter cloaceae* and water hyacinth on finger millet + soybean intercropping system had resulted in the yield advantage (LER more than 1.12). Application of water hyacinth (*Eichhornia crassipes)* at 2 t/ha gave significantly higher grain yield of finger millet and 1.1 t/ha of soybean. Seed inocculation of *Enterobacter cloaceae* had no significant influence on growth and yield of finger millet.

In Red Typic Haplustalf or Black Typic Chrombostert soils were applied with biogas slurry, compost or coir pith at rates equivalent to 10 t/ha with or without 75% or 100% of optimum NPK rates (90 kg N +45 kg P+45 kg K/ha). Grain yields were higher from black soil than from red soil. Among the organic fertilizers, coir pith + 75% NPK gave the highest yield on red soil and coir pith + 100% NPK gave the highest yields in black soils. Organic amendments increased yields compared with 100% NPK on red soils but not on black soils. Plant nutrient content was higher on black soils than on red soils. Compost + 75 or 100% NPK generally gave the highest nutrient contents (Lavanya and Manickam, 1993).

Application of tank silt

Parasuraman *et al.*(1998) evaluated the influence of tank silt during the rainy season of 1992-94 in Tamil Nadu on finger millet, sorghum and groundnut. A total of 100 tonnes of tank silt was applied once in the first year. Then 50 tonnes silt in the first year and 25 tonnes in the second and third years or no tank silt. Different combinations of inorganic fertilizers and farm yard manure were also applied . Crop yield and profitability were highest when 100 tonnes of tank silt per hactare was applied. Further, yield had increased when recommended rates of inorganic fertilizers were combined with 10 t FYM/ha.

Combined application of inorganic fertilizers and organic manures

This combination was studied to evaluate its effect on soil productivity and sustainability under wheat-ragi system at Almora, Uttarkhand (Himalays). Nutrient sources were applied to wheat crop and ragi was taken next on residual fertility. After a three year study, it was found that all the nutrient sources were equally effective in influencing the yield of wheat crop as testified to the good residual effects of organic fertilizer sources. Soil properties also improved under organic nutrients (Singh and Chauhan, 2002).

A similar study was made in Western Himalayas in Nepal by Acharya *et al.* (1999) on maize-ragi rotational system. The treatments were: Control with no fertilizer application; farmers' method of using organic manure only; farmers practice combined with half of inorganic fertilizers and organic manure and each one of them with half recommended rate. The farmers' pratice of inorganic fertilizers was based on 90:30:30 kg NPK/ha for maize and its residue for finger millet. The farmers' practice of organic manure was calculated on the basis of N concentration in the FYM to supply 90 kg N/ha. Results indicated that the farmers' method of the use of inorganic fertilizer gave the highest maize grain yield of 32 t/ha and 22.16 t/ha in the first year and second years, respectively. But the finger millet did not respond to the residual effect of inorganics, while it did get good results from the organic manure applied plots under the maize-millet cropping system.

Varalakshmi *et al.* (2005) evaluated the impact of diffrent fertilizer recommendation practices in Alfisol soils at Bangalore on changes in organic carbon, available N, P and K status and the yield in the groundnut- finger millet cropping system. The yield of both the crops was the highest under the recommended rate of fertilizers in combination with 7.5 t/ha of FYM. The organic carbon, available N,P and K contents of soils and its fertility status had improved.

Micronutrients

Response to $ZnSo_4$

During kharif season of 1982-84, trials were conducted under rainfed condition in Kolar district of Karnataka. Variety Indaf .8 was applied with NPK fertilizers from 0-90 kg N + 60 kg P + 60 kg K in various combinations along with 25 kg Z_nSo_4 with the highest rate of NPK. The highest average grain yield was obtained with 90kg N+ 60g P + 60 kg K+ Z_nSo_4. However, 60kg N+30kg P+30kg K /ha, gave the highest benefit-cost ratio (Purushotham *et al.* 1994).

Response to sulfur

Vaiyapuri and Sriramachandrasekhar (2004) of Annamalainagar, Tamil Nadu applied sulfur at the rate of 15,30 and 45 kg/ha through four sources : ammonium sulphate, potassium sulphate, gypsum and iron pyrite. Irrespective of the sources, the growth and yield of ragi increased with sulfur levels. Addition of sulfur at 45 kg/ha through iron pyrites produced highest plant height of 100.8 cm, 183 tillers/ m2, leaf index of 4.3, 12 fingers per head-1, 3.7 g of earhead weight, 1154.5 grains per head, grain yield of 3.7 t/ha and straw yield of 5.75 t/ha as compared with other sources of sulfur. The increase over the control at 45 kg/ha of sulfur through iron pyrite was 27.5%. Application of Mg, K and Ca on Mg uptake, protein content and yield of grain at Coimbatore revealed that 50 kg Mg/ha and 16.8 t ca/ ha gave significantly higher grain and straw yields. Mg uptake had significantly increased and grain protein content also increased by 15.9% over control.

In a pot experimen, finger millet was given equivalent to 0 -150 Kg Mg, 0 or 100 kg K_2O or 18.6 t lime/ha. After harvest of the first crop, the second millet crop was grown in the same plot to find out the residual effect, if any. Results indicated that there was a response in terms of yield to residual effects to 50 Kg Mg/ha and to lime, but not to K. There was a significant interaction between Mg and K. Uptake of Mg had increased by the application of Mg and lime. Crude protein content in the grain increased by residual Mg (Mathan, 1997).

Follar application of fertlizars

Foliar application of urea with 0.5% concentration with a spray volume of 100 gal/acre was tried by Narayan (1959) on maize and ragi crop. One spraying of urea increased the grain and straw yields by 5.3 and 9.9%, 2 sprayings at fornightly intervals gave 8.2 and 11.2% increase, respectively. Puttuswamy *et al*. (1976) tried liquid fertilizers on vari. *Purna* and found that 75% of NPK (recommended dose) along with 2 sprayings of *Navaras* at 0.25% concentration resulted in better yields. Navaras treatment induced more number of tillers and earheads per plot.

Rajan and Rao (1964) reported that there was increase of 550 kg/ha in grain yield when Zn was sprayed at the rate of 1.12 kg/ha in the form of Z_nSo_4. Presoaking of seeds in 4% Z_nSo_4 solution also increased yields (Kumaraswamy and Patil, 1977). Bhagyaraj (1967) reported that foliar spray of P and K on Rhizosphere microflora generally suppressed the bacterial population. However, the fungal population increased with N and P sprays.

Combined effects of potash foliar sprays at the concentrations of 0.5 and 1.0% and also soil application against blast fungus (*Magnaportha grisea)*, both in the pot culture and also in the field in Tamil Nadu showed that both the treatments reduced incidence of the blast disease. However, soil application of 30 Kg K_2O/ha combined with 1% foliar spray of KCl_2 resulted in maximum reduction in disease incidence and also gave highest grain yield (Murugesan *et al.,* 1995).

Response to cycocel

When ragi seedlings were dipped in 0.01 to 0.001 molar cycocel solution before planting as well as the same concentrations sprayed on the plants after 20 days of planting resulted in higher grain yield upto 31.8% (Veerasekharan et al. 1971).

Uptake of nutrients during crop growth stages

Sadasiviah *et al.* (1986) observed that absorption of P by finger millet was markedly different from that of N. Absorption of P gradually increased upto 74 days (tillering phase) and then tapered out. About 86% of P was absorbed before flowering. On the other hand, the uptake of K was more from tillering stages to grain formation stage. But by maturity stage, it declined; whereas absorption of K, starting from grain filling, continued upto grain maturity to the extent of 55%. However, 46% of total N and 51% of total K were translocated to the grain, while 75% of K remained in the straw (Nagraj and Kulakarni 1997).

Physical changes induced by mineral, organic and industrial amendments on vertisols (black soils)

Mathan (2000) reported form Coimbatore, India that efficacy of soil amendments on physical changes in black soils was graded in the following order: organic amendments, industrial wastes, mineral wastes. Within each group, the order of efficacy was: 1) Organic poultry manure> farmyard manure> maize straw> cotton wastes; 2) Industrial wastes: lime sludge> furnace slag> cement dust; 3) mineral amendments: gypsum> magnasite> tank slit. Incorporation of amendments significantly resulted in both density and soil strength and increase in hydraulic conductivity, stability index, aggregate stability and available water content. Higher grain and straw yields of finger millet were obtained with pig manure and municipal compost-treated plots relative to control.

Nitrogen uptake (symbiotic effect)

Symbiotic nitrogen contribution by nodulated soybean and non-nodulated soybean and ragi was studied by Chandel *et al.* (1988) at Pantnagar, Uttarkhand, India, in which non-nodulating soya variety Lee was intercropped with 1 or 2 rows of nodulating soybean, cv. Shilajeet, or given 20,40, 80 or 160 kg N/ha. Seed yields of 1.73, 2.00, 1.38, 1.69,1.94 and 2.23 t/ha, respectively, were obtained compared with 1.43 t/ha in pure stands without N application. Increased N uptake due to the association of 1 or 2 rows of Shilajeet soybean was 61.8 and 73.1 kg/ha in non-noudlated soybean and 32.0 and 45.1 kg/ha in ragi, respectively. Shilajeet in pure stands gave seed yields of 2.11 t/ha; N uptake by Shilajeet and Lee in pure stands without N application was 231.6 and 103.5 kg/ha, respectively.

Interculturing

Rajeevkumar *et al.* (2000) from Dholi, Bihar reported that overall growth and yield attributes of ragi crop increased with the increased level of interculturing except grain density. While there was an increase in grain yields, yields of straw and harvest index, protein content had not increased significantly. Further, additional levels of nitrogen application increased significantly the overall growth and yield components upto 40 kg N/ha, except grain density. Grain and straw yields, harvest index and protein content of the grain also increased.

Farmers in Karnataka use local wooden hoe (*Chippakunte*) for intercultivation operation after few days of sowing the crop in rainfed areas. However, Gowda and Dhananjaya (2000) tried the improved bent tyne sweep hoe in Bangalore. This was found to be superior to the farmers own method in conserving soil moisture at flowering and grain filling stages of the crop. During critical crop growth stages, the average soil moisture after interculturing with the improved blade and bent tyne sweep hoe was as much as it was when interculturing was done with *Chippakunte* followed by hand weeding. Among improved hoes, the bent tyne sweep hoe was superior to blade harrow in forming soil tilth and furrows. Moreover, the improved bent tyne sweep hoe controlled weeds more effectively. Highest grain yields were obtained when the bent tyne sweep hoe was passed twice.

Different intercultural implements like two tined indigenous harrow and improved two tyned harrow were tried at Bangalore by Murthy and Gowda (1993) to asses their efficacy on plant growth, yield and weed control in finger millet under rainfed condition. Improved harrow reduced weed density and growth and increased grain and straw yields as compared with traditional weeding methods with harrow. Nearly 80.34% of weeds were controlled when the interculturing was done with improved harrow and passed twice as against control (harrowing with traditional harrow), which was upto 61.47%. Grain yields of 2.77 – 3.20 t/ha and 2.60 – 2.70 t/ha, respectively, were obtained. Cost-benefit analysis indicated that the improved harrow gave 53% increase over the traditional method.

Cultivation in coastal region

Out of seven varieties tried at Karaikul in Puduchery (East Coast of India) during 2004, variety CO.13, Indaf.8 and GPU.26 had recorded higher plant height and dry matter production and the other yield attributes like number of earheads per m^2, length of panicle , number of grains per head and grain weight /m^2. Among 3 varieties, CO.13 gave the heighest grain yield of 2.0 t/ha, followed by Indaf.8 with 1.9 and GPU.26 with 1.93 t/ha. There were no significant yield differences between these varieties (Veeraputhiran *et al.* 2000)

Integrated nutrient management

Nitrogen balance and organic carbon status of soils in soybean – finger millet cropping system as influenced by integrated nutrients management were studied for two years under rainfed condition in Kharif seasons of 2002 and 2003. It was found that application of 50% N + 10 t FYM/ha recorded the highest N uptake by soybean (112.6 kg N/ha), followed by 105 kg N/ha – 50% N+50% N through green leaf manure + FYM + biogass slurry + poultry manure and 100 kg N/ha under 50% N + 50% N through poultry manure + biogass slurry + green leaf manure + crop residue compost. The same trend of N uptake was observed in finger millet also. After finger millet crop, in both the years, the actual nitrogen balance was in 100%N + 10 t FYM followed by 50% N + 50% N through green leaf manure + FYM + biogass slurry + poultry manure and 50% N through poultry manure + green leaf manure + FYM+ crop residue compost. Net gain of nitrogen was recorded in 50% N + 50% N through poultry manure + FYM + biogass slurry + crop residue compost accounting for 166.9 kg N /ha followed by 50 N + 50 N through poultry manure + FYM + biogass slurry + green leaf manure (166.6 kg N/ha.). Highest net loss of N was found in absolute control, which was as much as 30.9 kg/ N /ha. Highest organic carbon percentage was recorded in soybean with 100% N + 10 t FYM (0.51%) followed by 50% N + 50% N through poultry manure + FYM + biogass slurry + crop residue compost (0.50%). Similar results were obtained in finger millet. Application of 50% N + 50%N through green leaf manure + FYM + biogass slurry + poultry manure also performed better in improving the organic carbon status in both the crops (Kumar *et al.* 2006).

Studies made at Sau Paulo, Brazil during 2001-02 to evaluate the effect of the anticipation of soybean fertilization on 1) dry matter yield and nutrient uptake of finger millet and 2) dry matter yield, nutrient transport and grain yield of soybean cultivation after finger millet revealed that anticipation of the soybean fertilization did not interfere with the dry matter yield, grain and nutrient transport by soybean. Finger millet yield responded to the soybean fertilization by increasing its dry matter yield and nutrient uptake. Fertilizer management for the optimization of the sowing process can be used to plant the soybean at the proper time (Francisco *et al*. 2007).

During rainy season of 1989-90, Arunachalam *et al*. (1995) tried at Killikulam in Tamil Nadu integrated nitrogen supply system for finger millet. Variety K.7 was given 60 kg N/ha alone or 60,45 or 30 kg N + seed and soil inoculation with Azospirillum, or application of 5 t FYM /ha or 45 or 30 kg N + FYM + Azosipirillum, or FYM or Azospirillum alone. It was found that grain yield was the highest with 45 kg N + FYM + Azospirillum (4t/ha). But it was not significantly different from the application of 60 kg N + Azospirillum (3.9 t/ha).

Raman and Krishnaprabhu (2004) from Annamalai University in Tamil Nadu reported the results of study on the effect of integrated nutrient management on nutrient uptake and yield of finger millet cv. CO.13. Among others, the integrated use of inorganic fertilizers with vermin-compost, bio-fertilizer (Azospirillum 2 kg) and foliar application of chelated zinc resulted in an additional beneficial effect over the sole application of inorganic fertilizers. It was concluded that integrated nutritional management technique held promise as an appropriate technology for achieving higher yields in finger millet.

Correlation and regression studies

Correlation and regression analysis in finger millet as influenced by the application of different organic nutrient sources in combination with inorganic sources was made during kharif seasons of 2002 by Kumar *et al*. (2006). Results revealed that grain yield was positively and significantly correlated with growth parameters like leaf area

(0.92) and total dry matter accumalation (0.98) and the yield components like productive tillers (0.86) finger length (0.90), grain weight per ear (0.97) and 1000 grain weight (0.65). Similarly, nurient uptake of N (0.91) and K (0.86) also registered correlation with yield.

Strain - specific salt tolerance of Azospirillum

Three salt-tolerant *Azospirillum brasilensis* were isolated from roots of finger millet grown in saline calcarious soil and were characterized by Rai (1991) in Uttarpradesh, India. The effect of various salts on growth and nitrogenase activity of these strains was tested. Strain STR.1 was more tolerant at higher concentration of SO_4 / $CaSO_2$ and HCO_3. Bicarbonate was more toxic. The content and concentration of root exudates of finger millet genotypes were different and chemotoxis to sugars, amino acids, organic acids and root exudates were strain-specific. Significant interactions between strains and genotypes of finger millet resulted in different responses of nitrogenase activity, endo- and exo-rhizospheric population, dry weight of root, shoot and grain yields.

Water requirement of finger millet

Finger millet has been widely grown in India from times immemorial under rainfed conditions. Its water requirements is relatively small, around 300 mm of rainfall well distributed during the crop growth period of 100-110 days. However, irrigated crop requires more water. Nevertheless, water requirement of the crop is estimated based on the total amount of water required for the proper raising of the crop in a given period of time and method. Apart from for just growing of the crop, it requires for the associated operations like land preparation, possible leaching losses and such other consumptive use of other economically unavoidable losses. Further, irrigated crop needs for nursery raising and transplanting. It also depends upon the rooting habit, moisture extraction, method and frequency of iriigation, soil type and fertility and climatic factors during cropping seasons, which are highly variable with the seasons (Chinnavenkatareddy and Patil, 1977).

Consumptive use and water-use-efficiency

Consumptive use of water by plants include water used by evapotranspiration, growth and development. It also includes the soil moisture evaporated from the adjacent soil and the precipitation intercepted by plant foliage. It varies with soil types, seasons, variety, stage of growth of the plant and cultural practices inclusive of inter-culturing, types of mannure used and weed management.

Seasonal effect

At Siruguppa in Bellary district of Karnataka during summer season, the crop needed 7 irrigations accounting for consumptive use of 43.7 cm water from transplanting to maturity (Anon., 1970-73). Vasanthkumar (1975) estimated the consumptive use at Bangalore during summer at about 51.7 cm. Whereas, the same during kharif season was around 45 cm (Havanagi *et al*. 1972). At Coimbatore in Tamil Nadu, Kaliappa *et al*. (1974) estimated 45 cm during rabi (post-kharif season) and that the same at 39 cm during kharif season (Sivanappan and Balasubramanian (1974). The obvius variation in consumptive use of water between seasons could be due to higher temperetures, long days, low humidities, hot summer days and high winds. Transpiration and evaporation losses increased leading to higher consumptive uses in summers.

Varieties

Vasanthkumar (1975) reported higher water consumptive use for long duration variety TAH.14-26 than a short duration variety EC.4840. However, the variety TAH.14-26 recorded higher yield of 3.9 t/ha with low water-use-efficiency of 7.47 compared with EC.4840 having WUE of 7.51. Moreover, TAH.14-26 was a tall variety with more leaf area and hence more water loss through transpiration than EC.4840, a dwarf variety. Havanagi *et al.* (1972) found that a variety *Sharada* was most efficient compared to *Purna* and local varieties. Vanagamudi *et al*. (1990) observed that the var. CO.12 when irrigated at the cumulative pan evaporation reached 56, 67 or 83 mm, which are equivalent to irrigation frequencies of 8-9 (11, optimal), 10-11 (12, below optimal) and 12-13 day (13, sub-optimal), respectively, 11 and 12 treatments induced early flowering and maturity, which led to higher yield, improved quality and storability of seeds and reduced fungal contamination in storage compared with 13.

Response to moisture regime of the crop studied at Coimbatore, (Tamil Nadu) during rabi seasons (winter of 1985-86) and 1986 kharif (monsoon) season, var. CO.11 was given 0-200 kg N/ha and 5 different irrigation treatments. Yield increased significantly with increasing N rates upto 80 kg/ha and was highest with irrigation at an irrigation water: cumlative pan evaporation ratio of 0.6 (Rao. *et al.* 1992). Similarly, nutrient uptake of 0.91 N and 0.86 of K also registered positive correlation with yield.

Yield response factor (KY) for yield prediction under limited water supply was studied by Rao and Subramanian (1989). The yield response factor (KY) was used as a measure to study the impact of evapo-transpiration deficit on crop yield. In trials with finger millet, irrigation with 5 cm water / irrigation at irrigation water depth : cumulative pan evapotation (IW:CPE) ratios of 0.9, 0.6 and / or 0.3 were applied during a) sowing to panicle initiation, b)panicle initation to flowering and c) flowering to maturity periods in order to judge the sensitivity of growth stages to water stress using the KY factor. The KY values were high under severe stress (irrigation at IW:PCE ratio of 0.3). The highest KY value of 1.81 was observed in crops subjected to water stress during c) after receiving frequent irrigation during (a) and (b). A KY values of 1.01 was observed in crops subject to water stress during (a) and (b) with frequent irrigations during (b). The lower KY value in this trial was ascribed to the fact that plants adjusted gradually to water stress.

Effect of irrigation and mulching practices

Nagaraju and Wahab (2001) at Annamalainagar during June – September, 1988 and February – May 1990 studied the effects of irrigation at 0.6 and 0.9 IW/ CPE and irrigation at vegetative stage, vegetative and flowering and maturity stages as well as mulching with 2 cm thick with and 10 cm thick sugarcane trash. Variety used was CO.13. Irrigation was 550 mm deep. In 1988 and 1999 at 0.9 IW/ CPE and 0.6 IW/CPE along with 10 cm thick sugarcane trash gave the greatest plant height at harvest, number of tillers per plant, leaf area index at 50 days after sowing, dry matter production at harvest and grain and straw yields. Water-use-efficiency was higher under lower moisture regime (i.e., one irrigation at vegetative stage). The highest net return was obtained with irrigation at 0.6 IW/ CPE along with thick sugarcane trash mulch.

Use of effluent water from textile dyeing industry

Vijayakumari (2005) studied the response of ragi crop to irrigation by the effluent water from textile dyeing industry. Normal water was used for comparison. Plants were irrigated with 25, 50, 75 and 100% effluent water in a pot experiment. Plants with 25% effluent water showed maximum growth rate in root length (44.8 cm), shoot length (76.9 cm), leaf length (50.83 cm), root volume (9.8 cc), fresh and dry weight of shoot (25.9 and 1.2 g, respectively), fresh and dry root (5.6 and 0.89 g) after 30 and 60 days of sowing. Seed germination was very much affected at all concentrations against 100% pure water treatment.

Crop Weather models

Influence of selected weather parameters on biomass production in ragi was studied by Ganesan *et al*. (1988) at Bangalore during 1982–85. In that the relationship between biomass production in finger millet, cv. Indaf.5 and growing degree days (GDD), pan evaporation (EP) and evapotransperation (ET) was worked out. FW and DW were determined at 14 days intervals commencing from 20 days after sowing. ET values were obtained from gravimetric lysimeter measurements. Weather data were accumulated from the date of sowing to each day of biomass observation for each of the experiments. A simple regression equation was derived for biomass in combination with the accumulated values of GDD, EP and ET for kharif (monsoon) and summer seasons separately and for all the seasons pooled together. Four equations (Y= a + b log X, Y = ea + bx, y = ea + log x and y = a + bx, where y = biomass production in quintals/ ha and X = GDD or EP or ET) were considered to relate to biomass and 3 weather parameters. The third equation was the most satisfactory followed by 2nd, 4th and 1st. Correlation coefficient for individual seasons was highly significant. For individual seasons, r value of GDD vs. fresh biomass was 0.91 and for pooled data it was 0.82. Value for EP vs. biomass in individual season was 0.851 – 0.957 and for pooled data it was 0.82. Correlation coefficient of dry biomass and pooled data were lower than those of fresh biomass and individual seasons. Whereas r values were similar for both DW and FW. The increase in biomass was proportional to Delta X and Y, and inversely proportional to X.

A measure of influence of weather on crop production in ragi studied by Ramachandran *et al.*(1989) observed that ragi sown in kharif season of 1984-85 on 3 dates revealed that correlation of grain yield with rainfall, temperature, Relative Humidity, sunshine hours, evaporation and wind speed during the growth period was positively correlated with rainfall and mean daily minimum temperature.

A suitable statistical crop weather model to study the growing degree – days (GDD), sunshine hours (SH) and actual evapo-transpiration (AET) on crop growth during different phenological stages and to predict the final grain yield of finger millet was developed in the University of Agricultural Sciences, Bangalore, during kharif season of 1992-98. A greater influence of AET on grain yield was observed during ear emergence. Higher GDD was favourable during all the stages except at tillering. A good agreement of 95% was observed between the predicted and observed yield of finger millet (Rajegowda *et al*. 2000).

The effect of varying weather conditions on yield of finger millet variety A.404 studied for 19 years (1985- 2003) in Jharkhand, India revealed that it varied from as low as 15.37 q/ha in 1995 against as high as 30.93 q/ha in 1992. The highest yield was obtained under lower crop period rainfall of 963.5 mm; whereas, comparatively higher amount of crop period rainfall of 1614 .3 mm produced the least grain yield of 15.37 q/ha. Crop period rainfall from 1985-2003 varied from 764 to 1614 mm comprising of many good and many bad rainfall years. Still the crop invariably produced above 15 q/ha. The crop grown in and around 2 IMD lysimeters exhibited an average ET loss of 218 mm from transplanting to maturity. For direct sown crop of finger millet, this requirement did not exceed 290 mm (Haider and Wadood, 2005).

A total of 257 genotypes of finger millet was studied at high hills of Garhwal, Uttar Pradesh, India by Bandyopadhyay (2001) under low atmospheric temperature and rainfall condition during 1994-98. Cumulative temperature and precipitation at the pre-flowering period recorded significant association among themselves and with days to 50 % head emergence, while the effect of temperature and the number of rainy days at pre-flowering stages constituted negative significant association with grain yield, days to maturity, thermal time for maturity and precipitation received at post- flowering period. An increase in total rainfall and number of rainy days at pre-flowering period brought down the air temperature, which in turn increased the degree days for 50 % head emergence and number of days required for 50% heading among finger millet genotypes, while it decreased the physiological production capacity of cultivars by subsequent reduction in thermal times for effective grain growth and days to maturity as well. The number of rainy days at pre-flowering period, rather total amount of rainfall received during the vegetative period of crop growth had invariably affected grain production. Thermal time at post–flowering period showed significant positive correlation with both days to maturity and grain yield. Regression analysis revealed that days to maturity and thermal time for day temperature at post–flowering period registered significant negative and positive regression coefficient values, respectively, on grain yield.

A Stoichiometric crop weather model that could be used to predict the growth of figner millet and grain yield based on dry matter accumulated was developed by Muralidharan and Rajegowda (2002).

Multiple linear regression equations relating to the growing degree days (GDD), sunshine hours (SSH), actual evapotranspiration (AET) and initial biomass during each growth stage with the total dry matter accumulation and grain yield were generated using field data collected during 1992 to 1998 in Karnataka, India. Analysis of the regression coefficients revealed that higher GDD was favourable during tillering, ear emergence and 50% flowering stages, while AET was favourable during tillering and grain formation stages. SSH had a positive effect during harvest when GDD was also highly significant. During 50% flowering and grain formation, SSH had a negative impact on grain yield. During the tillering stage, AET showed a positive effect on the crop. The model accurately predicted the total dry matter at the end of each growth stage as well as the yield with 97.6 and 98.9% efficiency for the first and second growing dates, respectively, during 1999 trial.

Weed management in ragi / fingermillet

Weeds offer stiff competition to agricultural crops in general and ragi in particular. They aggressively grow right from the day of germination of ragi and continue to pester the crop till late in the crop growth stage. Ragi being predominantly a dry land crop, it is considered a low value crop in its esteem in the general perception of the people. Modern scientific methods, both mechanical and chemical, have not become popular because of knowledge-deficiency or cost-ineffectivity. So much so, weed control or weed management is of least priority for majority of the farmers. Consequently, they have not been able to derive the full advantage of the high yield potentialities of modern varieties of the crop. Traditional methods have not lent much help because they are labour-intensive besides being scarcer. Nevertheless, it forms a part of the package of the crop production systems and some progress has been made in weed management system. But its advantage had not been fully availed of by many a farmer.

Traditionally, a 4 tyned wooden harrow is passed within a period of 8-10 days after sowing the crop. If this operation uproots a few of the

weed plants, it equally does the same to the young crop plants too. Likewise, a second operation is also being done approximately between two to three weeks. In this process there is always a risk of loosing some plants. This leaves a gappy patches in the field. Following this, hand weeding is also being done within a month of the crop growth period. Even then total weed control is a wishful proposition. Crop loss due to weed competition under rainfed condition was estimated at 48.8% (Lingegowda *et.al.* 1986)

In this context some innovative methods have been worked out and some encouraging results have emerged. Krishnamurthy (1969) and Anon. (1970) had found that spraying of some herbicides like 2,4-D were effective. Nodoubt that this chemical had some hormonal effect too besides checking the weed; but it had some abnormal side effects like swelling of basal nodes and slight twisting of young leaves. Inspite of these disadvantages. 2, 4-D sprays at the rate of 1 kg a.i. /ha was effective not only at pre-emergence as well as at post emergence– stages. It also produced more number of earheads, more fingers per head as also higher grain weight per plant.

Nyende *et al.* (2001) observed that severe competition was offered by *Digitaria sealram* (D. *abyssinica*), which was a common weed in Uganda (Africa) and was difficult to control. Yields of the broadcast-sowing fields with one hand weeding were very low. But with the second weeding after 4 weeks of sowing, yields increased by 44.7%. Yields were also increased by row spacing of the crop combined with one hand weeding. However, because of inadequacy of farm labour coupled with relatively high wages limited the popularity of this practice.

At Berahampur in Odisha, India, Jena and Tripathy reported that two hand weedings at 20 and 40 days after sowing resulted in better grain yield under rainfed condition. Usual weed flora at Ranchi in Bihar was grassy, which could be controlled by earthing up the crop 35 days after transplanting (irrigated crop), and hand weeding at 20,40 and /or 60 days significantly reduced the weed menace and increased the yields (Yadav *et.al*. 2005).

The combination of wooden plouging followed by power tiller rotovating or cultivating inter-row cultivation by the improved bent tyne sweep or local hoe *Chippakunte* resulted in higher yields in the dry land crop (Gowda *et al*. 1998).

Sundareshan *et al.* (1975) had shown that under rainfed condition, the highest grain yield at Coimbatore was 3053 kg/ha when the field was kept free from weeds for the first 35-40 days after sowing.

The general practice followed earlier was passing wooden hoe fixed with 4 iron / steel tynes once or twice, once at 10-12 days and the other at 20-25 days after sowing, followed by one hand weeding at 30 days under dry land conditions. The irrigated crop (transplanted) received one or two hand weedings. Though the system seemed to work well, its high cost precluded it from becoming a general practice. Yields had significantly increased by one hoing at 20 days and another at 35 days at Dholi in Bihar (Kumar *et al.,* 2000). Whereas, two hoeings and one hand weeding resulted in higher grain yield. Field trials in Odisha during rainy season of 1984 and 1995 with four hand weedings at 20 and 40 days after sowing gave the lowest dry weight of weeds and higher grain yield of 2.12 t/ha.

Weed management in intercropping system involving ragi and soybean at Similiguda in Odisha during 1994-95 by Mahopathra and Haldar (1995), hand weeding and hoeing at 3,4,5, 6 or 8 weeks after sowing showed that the most critical period of competition was between 4 and 5 weeks of growth stage. Weeding at 5^{th} week was the best for getting good crop.

Conservation tillage for cutting the cost of production and check soil erosion in Japan, *inter alia* consisted of minimum tillage (MT) and conventional tillage (CT) following paddy with finger millet as cover crop. It was found that finger millet effectively controlled weeds (Samarajeeva *et al.,* 2006). Weed biomass was almost half under

minimum tillage without cover crop at the early stages of the crop growth. But the absence of finger millet under minimum tillage during 2008, significantly reduced the soybean yields. However, finger millet as a cover crop could be managed with a single mechanical suppression under minimum tillage with no yield disadvantage.

Chemical weed control was, however, found to be a better alternative. Viswanath and Krishnamurthy (1977) made a comprehensive review and observed that several chemicals had herbicidal properties. The important chemicals among them were 2,4-D sodium salt, Prometryn, Feroxon, Headamol, Paraquat, Eptam, Stam F.34, Simagine, Atrazine, Nitrofen, TOK–E, HCPA and so on. They were good either as pre–emergence or as post–emergence weedicides at various concentrations. Among them 2,4-D sodium salt was found to be the best both as pre-emergence and/or post-emergence spray. It not only checked the weed growth and also produced greater yields. In many situations, it was reported to be even equal to two hand weedings (Anon., 1974).

Among herbicides, 2,4-D 1 kg/ha gave 75% control of weeds and increased yields by about 150%. Whereas application of Pendimethalin 1 kg /ha, Thioben Carb at 1 kg/ha and Oxadiazon at 0.5 kg/ha, one day after sowing or hand weeding once resulted in 40-50% weed control and improved grain yield by 100% (Prakash, 1988). Post–emergence treatment with 2,4-D, Butachlor, Isoproturon, Metachlor or Diuron with or without earthing up 35 days after planting were effective in controlling weeds and increasing grain yields (Naik *et.al*., 1999). Reddy *et.al.* (1990) had shown that 2,4-D Na salt 1.5 kg/ha and Neburon at 1 kg/ha as pre–emergence treatment controlled weeds better than hand weeding subsequent to hoeing in the following year.

Integrated chemical and cultural methods further increased weed control and grain yields at reduced herbicidal rates. Pre emergence spray of 2,4-D Na salt alone or $CaSo_4$ gave markedly better grain and straw yields than control (Singh and Arya, 1999).

Kumar *et al*., (2007) had demonstrated that under irrigation at Bangalore, Butachlor and 2,4-D Na salt had resulted in higher net returns and benefit-cost-ratio as compared to two hand weedings and controls.

Integrated weed management involving earthing up, hand weeding and application of 2,4-D (75 kg/ha), Butachlor (0.75 and 0.5 kg/ha), Metachlor (0.75 and 0.5 kg/ha) and Diuron (0.75 and 0.5 kg/ha) was tried by Naik *et al.* (2000) to find out the extent of nutrient removal by finger millet and associated weeds in Karnataka during 1995 and 1996. Among others, Butachlor treatment with or without earthing up had less weed biomass and more dry matter in finger millet and highest uptake of N (89.92 kg/ha), P_2O_5 (16.25 kg/ha) and K_2O (74-78 kg/ha). Grain and straw yields in this treatment were higher than in other treatments.

In drill sown crop at Bangalore, Manjunath and Muniyappa (1991) found that Metaxuron at 0.75 kg/ha as pre–emergence spray combined with hand weeding 30 days after sowing had best weed control and gave highest grain yield of ragi. Similarly, Isoproturon at 0.25 kg + Metaxuron 0.37 kg/ha as pre–emergence treatment combined with inter-row cultivation 35 days after sowing and Metaxuron + hand weeding at 30 days gave good yields.

Reaction of finger millet cv. Indaf.5, maize cv. Deccan. 101 and cucumber cv. Guntur to the application of herbicides 2,4-D EE, Methabenzthiozuron, Oxyfluron, Fluchloralin, 2,4-D amine, Metaxuron and Isoproturon, Fluchloralin in the pot culture experiment at Bangalore during 1985, Isoproturon revealed the greater sensitivity to shoot and root lengths of finger millet than the shoot and root dry weight (Reddy *et al.,* 1990). However, cucumber was more sensitive to all the herbicides. But no residual effect of these herbicides was found in the soil even 125-138 days after application of these herbicides.

MICROBIOLOGY

Micro organisms, also called microbes, are a large and diverse group of biological forms on the earth and they are ubiquitous. They are the dominant form of life on the earth and would keep the earth spic and span by carrying out essential functions like decomposition of dead organic matter. They are helpful in understanding the basis of biochemical, physiological and genetic nature of life on the earth. They play important role in the fields of medicine, food and agriculture and agro-based industry. Among 6 major groups of microbes, those relating to agriculture, food and food industry are of utmost importance in farming enterprise.

The understanding of relationship of plants and microbes in respect of soil fertility microbial degradation of organic matter and its transformation into plant nutrients, plant and animal diseases do become pivotal in making farming a lucrative venture. Microbes encompass the whole of the plant kingdom, which, *vis a vis* includes finger millet or ragi (*Eleusine coracana)* too, which is an important dryland crop. Though it is predominantly grown under dryfarming conditions, it also comes up very well even under irrigated farming systems. Here the microbes have a great role to play to promote its yields and economics for the betterment of the farming community.

Six strains of root nodule bacteria, *Rhizobium* (GHR-2), *Bradyrhizobium japanicum (*Tall-110*), Rhizobium leguminosorum* (Vicide cn-6), *Rhizobium leguminosorum* (Strain-30), *Rhizobium caulinedays* (ORS-571) and *Sinorhizobium melilotic* (Strain-1) were tested for their effect on growth of sorghum and finger millet seedlings, cultivated asceptically in Leonardo jars with 1/2 strength Hogland nutrient solution by Matiru *et al.* (2005). Electron microscopy on 10 plants revealed the presence of all the six test strains on root epidermal surfaces as well as inside the tissues of inoculated, but not uninoculated, sorghum and finger millet plants. Bio-assays of the tested strains for indole acetic acid (IAA) showed that they produced biologically active concentrations of this (IAA) growth-promoting molecules. They ranged from 0.18 to 2.26 micro IAA per ml culture filtrate. This is the proof of the fact that rhizobial infection of sorghum and finger millet could promote increase in plant growth through release of metabolites. It would be improved through increase of P and K nutrition.

The cells of *Azospirillum brasiliense* strains established themselves endobiotically in the roots of finger millet. They were mostly found in cortical intercelluar spaces and vascular tissues (Agarwal and Tilak, 1988). But morphological and histological differences between micorrhizal and non-micorrhizal roots studied by Dass *et al*. (1988) showed that the diameter of the root cells, root caps, meristamatic zone of apex and R_2 region of the root were greater in micorrhizal plants than in non-micorrhizal ones.

Three salt tolerant strains of *Azospirillum brasiliense*, isolated from the roots of finger millet grown in saline calcarious soils were characterized by Rai (1991). The effects of various salts on growth and nitrogenase activity of these strains were tested. The strain STR-1 was more tolerant of higher concentrations of Cl– , $So_4/2$ – HCO_3 – , Bicarbonate was most toxic. The contents and the concentrations of root exudates of finger millet genotypes were different. Chemotoxins to sugars, amino acids, organic acids and root excudates were strain-specific. Under salt-stress, significant interactionas between strains and genotypes of finger millet resulted in different responses of nitrogenase activity, endo–and exo–rhizospheric populations, dry weight of root and grain yield.

Five *Azospirillum brasilense* strains were isolated from the roots of finger millet plants grown in acid soils of Bihar. They were characterized for their shape, size, strain-specific chemotoxin and nitrogen fixation ability in liquid medium containing different concentrations of $AlCl_3$ (0.20 mu M Al) and $MnCl_2$ (0.50 mu M Mn) at different P^H levels (Rai, 1991). Thes trains showed cross- resistance to neomycin and pencillin, but not to chloramphenical and tetracyclin. The use of various carbon substrates for nitrogen dependent growth and nitrogenase activity were derermined. Inhibition of associative nitrogen fixation and mineral uptake by acidity factors in acid soils could be overcome by manganese-mediated and alluminium cross resistance in *Azospirillum brasilense* strains FM-17 and FM 21 and suitable finger millet genotypes BR.2 and RAU.8.

Patel *et al*. (1993) tried in Gujarat the effect of different combinations of seedling root inoculation with *Azospirillum* at transplanting combined with nitrogen application. There was an incremenal yield of grain and the highest was 2.47 t/ha with 40 kg N/ha application. Whereas, it was 2.17 t/ha with the application of Azospirillum+20kg n/ha treatment. In *Azospirillum brasilense* treated seeds, soils and FYM during 1983 to 85, the yields were 1.60 to 1.67 t/ha as compared with 1.40 t/ha without inoculation. Application of 20 kg N/ha in combination with seed inoculation or both seed+soil inoculations, incresed the yields to 2.01 and 2.17 t/ha, respectively (Pradhan, 1990).

Band placement of enriched FYM 2.0 t/ha +100% recommmended N and K recorded at coimbatore, Tamil Nadu, higher microbial population–bacteria, fungi, and actinomycetes–with enhanced nutrient availablity. Significantly higher grain yield of 3269 kg/ha and 5908 kg/ha of straw were obtaied in comparison with the lowest yields in the plots applied with recommended doses of fertilizer alone as well as in the control plot. It had registered highest net return and benefit : cost ratio (Ramamoorthy *et al*., 2009). In 1989-90 at Killikulam, Tamil Nadu, Variety K.7 was given 60 kg N/ha alone or 65, 45 or 30 KgN/ha +seed and soil inoculation with *Azospirillum* or application of 5 tonnes FYM per hactare or FYM or *Azospirillum* alone. Grain yield of 3.9 t/ha was the highest with 45 KgN+FYM+ *Azospirillum* as against 2.10 t/ha in the control with no fertilizers (Arunachalam *et al.,* 1995).

At Nagamagala in Karnataka variety Indaf.8 was treated with 50:40:25 kg NPK/ha with or without seed inoculation with *Azospirillum* *brasilense* and *Azospirillum awamori*. The highest grain and straw yield and 1000 grain weight resulted from 100% recommended dose of fertilizer plus seed inoculation. But seemingly high results were not statistically significant (Shankarlingappa, 1993). Crop grown in plots from seeds inoculated with *Azospirillum lipoferum* or uninoculated was stressed by withholding water from 45th to 52nd day of growth. Water stress apparently decreased leaf nitrate reductase activity and increased proline concentration. Recovery of the plants from the effect of stress was more rapid in the inoculated plots (Jesudas *et al*., 1992).

Aluminium - tolerant (adapted) strains, Alr.1, Alr.2, Alr.3, Alr.4 of *Azospirillum brasilense* (RAU-3051) from acid soils were isolated through stepwise transfer to higher levels of Aluminium. One of the strains (Alr.3) showed more growth and greater nitrogenous activity at low p^H and 100 mu g $AlCl_3$ / ml than parental and other alternate strains. These tolerant strains showed cross resistance to neomycene, but not to streptomycene, except Alr-1. Aluminium adapted strains also tolerated elevated levels of manganese (75-130 mu g $MnCl_2$ / ml). The response of inoculation with Al-adapted strains was variable with different genotypes of finger millet in an acid soil. An initial low level of nitrogen was essential for maximum associative N_2- fixation, grain and straw yield. Also it appears that acid-adapted strains might be most suitable for nitrogen economy in acid soils having various P^H and associated factors of acidity (Rai, 1991).

Glomus

Experiments on ragi to assess the effects of *Glomus fasciculatum,* individually and along with biofertilizers, against nematode population (*Rotylenchus reniformis, Pratilarchus zea* and Meloidogyne sp.) showed that *Glomus fascicutum* individually as well as in combination with biofertilizers recorded higher yields per plot by reducing the multiplication rate of nematodes (Babu *et al*., 1996).

Tiwari *et al*. (1993) inoculated finger millet plants with 1 to 6 different VAM fungi, viz., *Glomus mosseae, Glomus epigaeum, Glomus fasciculatum, Glomus caledonium, Gigaspora calospora* and *Gigaspora margarita* and found that there was increase in plant biomass, height, leaf area and absolute growth rate. But the degree of effectiveness between VAM fungi varied significantly. Maximum root colonization and mycorrhizal efficacy was observed in plants inoculated with *Glomus caledonium*. Out of 5 host genotypes, HR.374, PES.110, Pe.4, PES.400 and PES.176, tested for mycorrhizal dependency against *G.caledonium* and HR.374 gave the highest plant biomass, micorrhizal efficacy and root colonization. And inoculation resulted in increased mineral contents, viz., phosphate, nitrogen, Zn_2 + and Cu_2 + and uptake in shoots.

Number of starch grains and levels of RNA and insoluble protein present in the root cap cells of finger millet infected by *Glomus fasciculatum* only colonized the critical region of the root and not absorbed in the stele. Leaves of micorrhizal plants showed an increase in the thickness, size of midrib veins, major veins, minor veins, mesophyll cells, motor cells and number of plastids (Doss *et al*., 1988). It was also shown that *Glomus fasiculatum* penetrated the lignified sclerenchymatous exodermal cells in roots of *Eleusine coracana* plants grown in inoculated soils. The dual inoculation of *Glomus fasciculatum* and *Pencillium funiculosum* or *Aspergillus niger* produced synergistic interaction , which resulted in improved growth and nutrient uptake in finger millet (Gopalakrishna *et al*., 1990).

RAPD analysis

Acetobacter diazotrophicus strains were isolated from finger millet, cultivated along the coast of Tamil Nadu in India, using a species-specific Oligonuleotide primer and PCR amplification demonstrated the presence of this bacterium directly in plant tissues proving its endophyctic nature ; but it was not found in non-rhizosphere soils. They were also characterized on the basis of typical morphology, electron microscopy and biochemical tests including nitrogen-fixing efficiency to assess their diversity. When RAPD analysis was performed on the isolates, they fell into two distint genetically related groups when compared with the type strain PA.15 (ATCC 49037). In view of the importance of finger millet in coastal region, associated *Acetobacter* strains might be agronomically important. Because, they could supply part of the nitrogen that the crop required (Logonathan e*t al*., 1999).

Fermented food Tape from ragi

In Japan fermented food Tape is produced for human consumption. To increase its sweetness and aroma, steamed glutinous rice was inoculated with ragi and incubated at 30^{0}C for 3 days. Microorganisms found in ragi were identified as *Rhizopus sp., Sacharomycopsis sp.,* and *Streptococcus sp*. Steamed glutinous rice was liquified and saccharified by the amylases produced by *Rhizopus* and *Saccharomycopsis*. Liquification was not caused by the amylase of *Saccharomycopsis* even though it produced high alph-amylase activity. A higher level of aroma was formed by inoculation of *Streptococcus* in a mixed culture of *Rhizopus* and *Saccharomycopsis* sp. (Suprianto *et al*., 1989).

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CROP PROTECTION

Ragi or finger millet has been an important gain crop grown under rainfed conditions in arid and semi arid tropics of Africa and Asia, where millions of small and marginal farmers inhabit with sub average economy. Being rain dependent it is always uncertain to get a good crop. Further, insect pests and diseases, particularly the latter, are always inimical to the crop. Standard plant protection measures are always a mirage, firstly because of the lack of knowledge and secondly due moors economic assets to invest on the crop. Thus, getting a good crop of ragi year after year is a kind of gamble. Evidently, therefore, it calls for cost cutting technologies to insulate the crop against the savaging pests and diseases, apart from managing droughts to the extent possible.

Plant protection deals with both insect pests of various kinds and equally varied types of diseases with regard to the farmer, there are over a dozen pests, which, when infest the crop, does damage to the crop to a varying degree depending upon the stage of crop growth (Puttuswamy and Channabasavanna (1977), Nagarajan and Channabasavanna (1977) and Jagadish and Musthak Ali (1983). However, only few of them are severe to cause economic losses.

Pests

Ragi stem borer

There are two types: pink borer (*sesamia inferens*) and Ragi white borer (*Saluria inficita*). Pink borer has been the most common pest on ragi. It has a limited host range: sorghum, wheat, sugar cane and rice. Krishna Murthy and Osman (1952) made a detailed study on the life history of this pest together with possible control measures including biological control.

Taxonomically, *Sesamia inference* walker, belongs to family Noctuidac and order lepidaptera. The genes

Sesamia was first deseribed by Gunee in 1852 and then sedescribedly Hampson in 1910. It has a manner of synomyms, perhaps as many as 10 (Puttaswamy and Channabasavanna, 1977). Geographically, it is distributed throughout oriental region and also spread eastwards into Pataearctic regions. But it widely prevails in India, Mayanmar, Srilanka, Malaysia, Japan, Thaiwan (Hampton, 1910) and South Korea (Bac *et al*., 1969).

It has a wide host range, which include dry and irrigated ragi, sugar cane, sorghum, rice, wheat and maize. Its frequence it, however is to irrigated ragi crop.

Its life cycle lies in daring more than 400 eggs between leaf health and stem in two to three rows. It was also observed to have laid 300 eggs in 5 masses along the margin of inner surface of the leaves. Eggs hatch in 4-9 days in summer and above 9-25 days in winter. The eggs are be mispherical 0.7 mm in diameter and creamy white in colour, which turns brownish and ultimately grey before batching freshly batched larvae are about 1.5 mm long and pale yellow and later turn completely yellow. The young larvae emerge from leaf sheath and disperse to neighboring plants. They bore with young seedlings and feed on the central tissues in the stem. Causing “dead hearts”. The larval period losts for 3, 6, 38 days. Pupation takes place inside the bored stem or under a leaf sheath on the stem. The brown pupae are about 14 mm long and losts for 10-14 days. The larvae period spreads over 31-38 days and the caterpillar measures 20-22 mm long and yellow in colour.

Ploughing of the stubbles of the previous crops more important to prevent the carryover of the inoculums from the previous crop. When the seedlings grow to a standard size, earthing up the crop minimized its infestation. Spraying chemicals like DDT and BHC seemed better than dusting. Other insecticides observed to be effective were 0.07% diazinon, 0.1% Dimeron 0.075% Bidriu 1% lebacid, 0.05% Parathion, 0.05% dimetheate, and 0.1% metasystex (Grist and Lever, 1969, Anon., 1975). The biological agents seen to be effective against the best were *Trichogramna minutim* and *Telenomus species ragi white stem borer.*

Ragi White Stem Borer

Saluria infinite walker belongs to family *Pyralidso* and order *Lepidoptera*

It was s specific best on ragi in south India (Ayyar, 1963). The caterpillar is cramy white in colour and bored into stem like ragi pink borer. It lodges at the lower parts of the plant, close to the soil surface. Its life cycle is exactly like that of the pink borer. It nupates inside the stem and the adult with emerges as a dark brown, medium sized more with a pole white bands along the margin of each fore wing. Unlike ragi pink borer, it is not a serials pest nevertheless, its control masures were the same as for pink borer. The mothers larve some attraction to light. Hence, light traps are put up in the measures the foci of the inocsslum, to catch them before they lay eggs.

Hemipterous pests

They are mostly earhead pests, which cause considerable damage to the crop by sucking the cap from the grains at the milky stage. This led to shriveled and empty grains. Osman and Putturudriah (1955) observed the attack of aphids *Rhopalorsipnum maidis* fitch on the earheads in Karnataka, India. In addition, Aphis arenac was also found on the earheads. A complete list of Hemipteros bests was given in Annexture-I in theis waper lay Nagarajan and Cahnnabesavanna (1977).

The other pests, though less important, were sorghum of all midge (*Cautasinia sorghicola*) reported from east Africa (Geering, 1953 and Barner, 1956). A cetanoid beetle (*Anatoma Stillata* Newwan) was found damaged earhead by Coleman and Kannan (1918) In Karnatak, India, Additionally, a *Myllocerus* Sp. was recorded feeding on the earheads (Anon., 1975[C]).

Economics of crop losses was estimates at Bangalore centre of the All India coordinated small millet improvement project ICAR (1975).

A sample of 10 plants from the variety PR.202 was taken and the number of insects present there was counted before the treatment was given with insecticides. Again counting was done after 30 days of treatment with BHC-10%, Carbaryl – 5%, endosulfan – 4% and Malathion – 5% applied as dust at the rate of 20 kg/ha. The average percentage of infested plants in the case of bugs ranged from 1.5 to 2.2 in the treated plants as against 3.2 in non-treated controls. Similarly, caterpillars and grey weevil populations in the treated plants varied from 1.5 to 3.0 and 0.8 to 4.4 respectively, in the control. The maximum grain yield from endosulfan treated (dusted) plots was 30.8 G/ha as compared to 26.0 Q/ha in control. It was indicative of the fact that, if control measures were taken at earhead stage, crop losses could be considerably brought down.

Jagadish and Musthak Ali (1983) reported the damage done by cutworm (*spodoptere exigua*). It has spread widly in India by defoliating plants in the nursery. The caterpillar was nocturnal habit. The larvae vid under clods during the day and became active during night. The adult moths was brownish in colour with white lined legs. The brownish – green larvae with wavy lines on dossal surface and yellow stripes laterally supate in the soil and emerge as adults in 7-11 days.

The other leaf feeding pests were block dialy caterpillar (*Estigmene bactinea*) and Flee beetle (*Chactonema fusaensis).*The larvae of black hairy caterpillar were gregarious in habit and voracious feeders on the leaves, they were generally black headed with haire all over the body. The flee beetle was dark blue in colour with enlarged haid femur. Adults mate holes in the leaves of young plants both in the nursery and also in the fields. The other leaf eating pests, which were occasionally feeding on the foliage were *Mouetepta sizuate,* the adults of weevils (*Myllocerus discolous* and *Myllocesus viridenous* (Coleman and Kaanuan, 1918) and the nymphs and adult of the wingless grass hoppers (*Osthacris simulans*).

Sucking pests

Sucking pests like *selizaphis gramineum*, found on the under suface of laves, Rhophalosiphun maidis infesting ceutsal whereas of leaves and *Hysteroneura setariae* suck cap from leaves and ears grasshoppers like *cicadulina bifunetata* and *Cicadutina Chanai* assume serious status in the early crop growth stages upto 35 days, especially in the nursery when the crop was grown under irrigation. In addition, these pests, apart from sucking cap, causing white speaklings and stunted growth were also known to transmit mottled streak virus. They were controlled by spraying parathion 0.025% or methyl demecron 0.05% or dimethoate 0.03% or monocrotophos at he rate of 0.01%.

Sometimes, mealy bug *Heterococcus rehi* was found with the leaf sheath of tillers.

Root aphid (*Tetraneura nigriabdominals* occasionally becomes pestiferosis on the crop. The pink gblobular small apohids accur in large numbers and suck the cap from the roots causing gradual witting and drying up of plants in the field in patches. The insect is parthenogenatic and viviparous and develop on grass all through the year after two or three generations, individuals gave rise to alate forms and then get dispersed. These produce young ones, which infest the root of ragi crop and other grasses. The pest could be controlled by drenching dimethoate 0.03% emission around infested plants. Also mixing crude oil in irrigation water was another method commonly followed to control this pest.

White gruls (*Halotrichia consanguinea*) severely damaged the roots in the months of July to September and caused considerable yield loss. In corporation of 10% BHC mixed with FYM at the rate of 45 kg/ha in the soil before transplanting could keep the pest under check.

During August – September, 1981, a coccinellida pest *Afidentula minima* was recorded for the first time as a post on ragi in Gujarat (India). Dusting with 10%BHC (HCH) or casbaryl was effective in controlling them (shah *et al*., 1990).

An incidence of *Helicoverpa armegera* was observed by Sharma *et al*. (1998) at ICRISAT, in Kenya. A trial was conducted to access the degree of damage with 23 high yielding cultivars at Kiboko, Kenya during 1994. The incidence of pest request from 8.0% in the varieties had 15% damaged heads genotypes with compact earhead had higher frequency of infestation than those with open or loose earheads. Timing of flowering of the crop had a significant influence on the pest attack. Since the chemical control was found ineffective, it was suggested to focus on developing resistant or less susceptible varieties.

A trial was conducted at Raichur, Karnataka during February, 1993 to assess the efficacy of various insecticides against leaf aphis *Hysteroneura Selaria* (Prabhuraj and Jagadish, 2001). Insecticides like monocrotophos 1%, chloropysifas 0.05% dimethoate 0.05%, dichlorvas 0.05% and carbofuran 3 gms were applied. Simultaneously, another experiment was conducted in August, 1993 to fixed out the efficiency of timing of carbofuson treatment on the pest. Results were very encouraging. Application of dichlosras, chlospysifos, monocrotophos and dimethoate effectively controlled the applied population upto third day in the treated plants. Carbofuron was effective in controlling aphids upto 20 days after application. But aphid population increased in carfofuson treated plants at 25,35, 45, 55 and 65 days, while there was no such increase with the plants sprayed on 75 days after planting.

Plant diseases

Small millets, including finger millet, have been the sources of staple food crops in the semi-arid and arid regions of the world. Some of them are lightly nutritious and thus they are known as "nutricereats" out of 4 million hectares of small millet crops, nearly 50% is covered by finger millet only. As for India, many states cultivate ragi as a staple dietary source. Besides, Nepal, Sri Lanka and Japan, several countries in Africa, such as Zimbabwe, Ugauda, Ethiopia, Kenya, Tanzania, Zambia and so on grown finger millet as a food crop.

In comparison to many others, small millets in general and finger millet in particular, are less frone to diseases and pests. Nevertheless, as many as 25 fungal, 4 visd, 5 bacterial and 6 nematode nathbagens are reported to insect finger millet crop with varying degrees of infectivity of all the diseased, blast, caused by *Hagnaporthe grilae*, dominates the rest, accounting for most of the annual crop losses in the world. In India, the loss caused by this disease is estimated at about 25%

The diseases of millets as a whole were extensively covered by Ramakrishnan (1963) and Pall *et al*. (1980). However whereas in ragi diseases as a whole have been exclusively dealt with by Anilkumar and his collegues in 2003 at AICSMIP located in the university of Agricultural Sciences, Bangalore, India. What is important is that it covers the literature emanation from different varts of the world , wherever ragi work has been going on. The present account of the work on the disease of ragi presented by this another, has been largely derived from this source.

Compared to many other crosses small millets in general and to some extent, finger millet in particular, are less frone to pests and diseases. Nevertheless, the finger millet is known to be damaged by 25 fungal, 4 viral, 5 bacterial and 6 nematode rqthageus, causing yield losses to a varying degree between them selves (Anil kumar *et al*. (2003).

Fungal diseases

Out of 25 fungal diseases reported on finger millet, blast disease cause by *phricularia Setaria* or *pyriculariq griseac* or *magnaportha griseas* is a most destructive disease resulting in heavy crop losses. It is very wide spread. In India, it is reported from Karnataka, Tamil Nadu, Maharashtra, Gujarat, Andhrapradesh, Oridssa, Bihar and Uttaranchal. It also occurs in Napal (Thompton, 1941), Sri Lanka (Park, 1932(, Malaysia (Burnett, 1949), Tangania (Wallacc and Wallace, 1948), Zambia (Muganga and Danial, 1995), Ethiopiq, Keny and Uganda (Dunbar, 1969, Anon., 1959, Adipola, 1992). The disease was reported from India for the first time from Tanjore delta, Tamil Nadu (Mc Rae, 1920) and subsequently from erstwhile Mysore state by Venkatasaan in 1937.

The disease after inflicts heavy crop losses. In Rampur, Nepal, the loss was reported at 100% (Batsa and Tamong, 1983). In Himalayan region at lower elevations (160m), it caused the loss upto 25.46% (Bisht *et al*. 1997). Ramappa *et al*. (2002) reported upto 50% neck blast and 70% finger blast during 2000 in Mandya and Mysore districts of Karnataka yield losses heaviest if the blight occurs at the seedling stage (Kulkarny and Govidndu, 1977).

Disease affects the crop at all stages of growth – from seedling to grain formation. In the nursery, desions are formed on the leaves, which are of spindle shaped and are of varying sizes. The sports were at first grayish – green in the centure with yellowish margin. Later, central portion turns whitish and gradually disintegrates underlined condition, an olive-grey over-growth of the fngus was seen in the central portion of the sports to begin with, the lesions are isolated but might coalesee soon, covering extensive areas.

Adult plants from either transplanting, broadcasting or drilled, lesions develop on the leaf blades. The apics of the infected leaves beyond lesions droop down and break. When the pathogen infected the stem, it causes blackening of the nodel region, extending upto 50 -100 mm on both th sides, penetrate in to the stem the main stalk below the lowest spike (the neck region) becomes discoloused and shrink in size to a length of one or two inches. This portion, being weaker, night make the earhang down or break from the stalk. This condition of the neck is known as “rotten neck” (Srikant kulkarni and Govindu, 1977) earheads, especially the sachis, are attacke by the disease grain formation might be distorted or at best a few shriveled grains are formed the most damaging phase of the disease, however, was when it attacked the neck region. Two or more inches or neck almost immediately below the head turns initially brown and alter black. An olivegreen growth of the fungus is noticed on this area (Anil Kumar *et al*., 2003)

If the infection coincides with seed setting stage, the grain development is totally affected resulting in seed sterility or if the infection is delayed, it would results in half or under developed seed.

When the pathogen attacks fingers, the infection is usually from special region downwards. The degree of infection is dependent upon the stage of infection and the weather conditions. At times, the entries or early entries length and breath of the earhead is affected, producing nothing. Pathogen, if attacks the grains, the resultant grains would be susivelled and blackened.

The nomendatural differences noticed earlier between *pyricularia orizae*, *p. sataria* and *p. grisae* were tested through a series of morphological and seriological studies. And named it *Magneportha grisea* (Ramakrishnan, 1948, Nishikada, 1917, Park, 1937, Hansford, 1943, Wallace 1950, Arunkumar and Singh, 1995a and 1955b, Prasad *et al*. 1998 and Anilkumar *et al*., 2008). However, Herbert (1971) named it as *ceretosphaeria grisea*. But later Yagashi and Nishinara (1976) suggested the genus Magnaporthe as the appropriate one and finally, it was named as Magnaporthe grisac by Yaegeshi and Udagawa (1978).

Magnaporthe grisac

It is a fungus, causing a blast disease in finger millet structurlle, its hypha is hyaline and septate. As the fungs gets oder, hypha becomes brown. Under high humid condition, large number of conidiophdes and conidia are produced, which give a dirty brown clolour to the lesions. Generally the gr4owth of the pathogen is more on the upper surface. The conidiophores may emerge either through stomata opening or directly from the epidermal layer. Conidiophores are simple, septarte and the bosal portion being relatively darker. Comidia are produced acrogenously, one after another and three celled the middle cell being wider and darker. Generally, the end cells germinate and give out germ tubes. The organism produces abund out dark coloured chlamy disposed in culture (Venkatarayan, 1937).

The pathogen grown luxuriantly on oatmeal, potato dextrose, bean meal and ragi meal agar. Among synthetic media, richard's medium promotes best growth (Srikant kulkarni and Govindu, 1976a). maximum growth was found at ph 6.9 and temperature at 30'C. However, the Somalian stsain required 12 to 35'c, optimum being 25-31'c (Mohamed, 1980), Glycagen and Sucrose produced maximum growth amongst carbon sources. Asparagin is the best nitrogen source, followedly glutamic acid, tryptobnan, annonium nitrate, potassium nitrate and so on. The fungus exhibited deficiency for biotin and thiamine (Srikant kulkarni and Govindu, 1976b, Suryanarayana, 1958 and Sadasivan and Subramanian, 1954) pyridoxine, inositol and nicotinic acid stimulated growth. Arunkumar *et al*. (1975) noticed the differential response of isolates from rice, ragi and pear millet to media, temperature, pH and light.

Arunkumar and Singh (1995a) studied the lipids and fatty acid pattern of these isolates of *Magnaporthe grisac*, viz., rice, finger millet and pearl millet. Differences in lipids and fatty acides patterns showed that rice and finger millet isolates were closer to each other in comparision to pearl millet kumar *et al*. (1997b) and Zeigler (1998) proposed that recombination might have taken place between isolates from rice and ragi in Himalayan region, where the two hosts had coexisted for central centuries.

Population of *Magnaposthe graisae*, that infect finger millet in different regions of Inisia, were analysed for these genetic diversity, fertility and maturing type distributions. From this it was appareint that the levels of fertility in isolates that infect ragi and grasses was high, while very few fertile rice isolates of the pathogen produced perithecia (Brina *et al*. 1999, Daynakar, 1999, Viji and Gnanamanickam, 1998).

Viji *et al* (2000) investigated DNA polymorphism of isolates of *Magneporthe grises* from India that were pathogenic to finger millet and rice isolates. The results showed that they were genetically isolated and distinctly different host limited groups. Cross inoculation tests reveled that they were host specific.

Isolates of *M. grisac* were capable of producing micro conidium and all kinds of sexual fertility, where some hermaphroditic, some male fertile and some female fertile (kato *et al.,* 1979). Yaegeshi (1977) noticed the presence of abnormal ascospores in crosses between strains pathogenic to rice and ragi.

Auxotrophic mutants of *Pyrienlaria orizac*, isolated from finger millet, were artificially produced by uv treatment and their linkage relationships were worked out through ascospore analysis. Auxotrophs of L. methionine, L – homoserine, L. serine, L.leusine and inositol were governed by one major gene, met-1 and met-2, Is, ser, len and iro, respectively. IBP resistance gene ibp lined with ino Met-1 and Met-2 showed the linkage relationship suggesting the same chromosome. In respect of other characteristics including mating type gene, no linkage relationships were found in the present analysis.

Veena Hegade (1996) studied variation among isolates of *P. grisac*, collected from different parts of India in respect of their virulence when tested against 6 resistant varieties. The most cirulent isolate was the neck isolate collected from Kanke (Bihar), followed by Anakapalle, Bangalore, Kanke (leaf), Berhampur (Orissa), Dholi (Bihar) and Coimbatore (Tamil Nadu). This type of variation among six isolates collected from different districts was observed by Ramasamy (1995). But the isolates from the variety Paiyur of Dharmapuri district showed abundant sporucation and high virulence.

Swamy Rao (1966) and Narayana Rao and Suryanarayana (1975) worked on toxin production by the pathogen, which was found to be pyriculal. Samanth Kumar (2002) and Sanathkumar *et al*. (2002a) found the production of six toxins by the pathogen and identified one of them as pyrichalarsin – H as important. The reaction of the varieties to the toxins was similar to theis reaction to the pathogen Samathikumar *et al*., 2002b).

Laburn *et al*. (1991) constructed a phenogram from RFLP data base on single copy probes showing that wheat and finger millet isolates were related to each other. Several repetitive DNA elements like MGR

586 have been reported in *Pyricularia* that have a rice specific pathogen genotype (Hamer, 1995). Similarly another repetitive DNA probe was found in a population of *Eleusine* isolates but not in isolates of other monocots (Dobinson *et al*., 1933). Tosa *et al*. (1995) studied distribution of retrotronsposam MAGGY in Pyricularis species isolated from various monocot plants. MAGGY was absent in finger millet in as much as that was found to be present in a high copy number in isolates from rice and foxtail millet.

Several studies were made to find out the possibility of gene flow from one host-specific species to another Yaegashi and Asaga (1981) studied inheritance of pathagenicity in crosses of *Pyricularia orizae* and *Pyricularia grisea* and concluded that the opportunity for gene flow between rice and finger millet genotypes on a common host was unlikely.

Collateral hosts

In host range studies in Maharashtra (India) had found that an isolate of pathogen from ragi also infected barley and wheat. Rice and Ragi pathogens were not cross inoculable (Tomar et al., 1994). However, Ramasamy (1935) observed *Bractaria mutica* and *Panicum repens* were collectoral hosts of ragi blast. In addition, it readily infected *Setaria italiea*, *Elucdine indica, Lolium multi forum, Festuca elator*, wheat, barley, Oats, Maize and soon. Hiremath and Sulladmath (1989) reported this on hybrid napier grass.

Losses due to blast

Amongst other diseases in ragi, blast is the most distructive one. MCRac (1922), while reporting this disease for the first time in India, gave an approximate estimate of 50% crop loss. Venkatarayan, (1947) put this estimate at 80-90% in else while state of Mysore in India. Whereas the loss in ugauda was reported to be around 10% (Anon., 1959). The ultimate loss in grain yield is due to the cumulative effect of reduction in number and weight of grain as well as considerable spike lot sterility (Rath and Misra, 1975).

The adverse effect of the disease could be accounted for by deereased germination of the seed, death of affected seedlings, damage to foliage of the seedlings me out for transplanting and so on. In the main field, the disease affects plant growth, tillering, panicle length, grain number and grain weight (Pall, 1977). Esele (1982) and Emchebe (1975) observed the crop being affected to the extent of 10 to 80%. Blast disease in Nepal destroyed the crop with 100% loss. (Batsa and Tamang, 1983). In India it is reported to be a regular feature for the disease to strike the crop resulting in an average yield loss of around 28% (Seetharam and Viswanath, 1983).

The plots affected leg blast were treated with some fungicides gave an increased yield ranging from 3.876% to 41.13% the highest incremental yield was from Bavistin treatment (Rao and Chaunamma, 1984). The combined effect of leaf, neck and finger blast resulted in the yield loss of 20.6%, 36.89% and 42.5% respectively. (Bisnt et al. 1985). Rao and Hegde (1987) reported that the increase in blast infection just by 1% in the neck and the finger reflected in the yield loss of 1.32% and 0.084% respectively. The mean yield loss in the varieties, VL-204, Purna , VL-101 and PR-722 was 33.15%, 34.30%, 9.9% and 4.76% repectively. (Sharma et al., 1988). Ekwamu (1991) observed significant reduction in grain yield in Uganda due to reduction in spiken let length, grain weight and number of grains herhead. In a two year trial, it was found that variety BM-1 suffered 54.7% yield loss, while BA-02 with 51.5% loss. The fodder yield lost was 42.6% and 5%, respectively (Haider, 1992). Viswanath and Channamma (1989) raised the crop year round at fortnighty intervals and found that neck blast incidence was maximum in August sown crop at Bangalore. Whereas in Almora, in sub-Himalayan region, the May sown crop was worst hit. In gashwal (Sub-Himalayan region), minimum temperature and rainfall showed a significant linear relationship with disease development as against the non-significance of the inpact of maximum temperature and relative humidity Bisht and Srivastava (1991).

In a two year study in Madyapradesh (India), the average minimum and maximum temperatures of 22'c and 29'c respectively. Coupled

with 85 to 99% relative humidity were found favourable for the disease development (Patel and Tripath, 1998).

Pall (1988) described the role of seed borne inoculum on blast incidence and severity. The infection immediately after flowering resulted in 76.82% and 70.14%, reduction in grain yield and 1000 grain weight, respectively. However, only 50% reduction of both grain yield and 1000 grain weight was observed with the infection occurring at milky stage. Late infection showed 5% reduction in both grain yield and 1000 grain weight (Ramappa, 2000e).

Cultural and nutritional effects

Investigations at Similiguoa (Orissa), revealed that blast disease incidence was more in direct seeded ragi crop than it transplanted crop. Presumably, it was attributed the over crowded plant populations, which provide optimal microclimatieal conditions for the disease to develop (Mishra et al.,1985). Besides, increased application of nitrogen was another season for the disease to flare up at Payur in Tamil Nadu. There was no significant reduction with the increased dosage of Potash, while soil or foliar application significantly reduced the incidence.

Mechanism of resistance to blast

- **Physical basis**

  Anatomical studies of infected as well as healthy plants showed that epidermis-cum-cyticle thicknets was significantly higher in the leaves of resistant genotypes. Where as stomatal frequency per mm^2 and size were significantly less than in highly susceptible varieties (Sanathkumar *et al*., 2002b). However, Jain *et al*. (2002) showed that leaf area, leaf angle, number of stomata, plant height and harvest index contributed more to the blast resistance.

- **Biochemical basis**

  Maheshkumar (2002) working with phytoalexin production plants found four different phytoalexins produced. Of These, oryzaaxelin was most effective. Blast incidence was positively correlated with grain protein content in all the environments. Cultivars with higher protein insects were susceptible to blast than those containing low protein contents. White grain cultivars, which were generally more in grain protein contents were more susceptible to blast than the brown seeded cultivars. Which were normally less in grain protein content (Dinesh kumar et al. 1885). The infection occurred with increase in protein inseed, but decreased in starch and ash. In all the cultivars, a glueolidase activity was higher and glucose content lower in the diseased portion of the neck (Pau, 1992) and this had resulted in an imbalance of total carbony dlotes (Pau, 1994). Significantly relationship between protein content and blast resistance. (Byregowda, 1999). There was a strong association between the seed colour with high seed protein, pheual, tannin with blast incidence. Sugar content and peroxidose activity had no influence on the blast occurrence (Ravikumar *et al*., 1991).

Somappa (1999) reported that certain biochemical contents in blast resistant variety GPU-28 and susceptible variety K-7 were at variance. The latter lead higher protein content. The reducing sugar content was higher in dry seeds, 25 days old seedlings and dough stage. Whereas in GPU-28, the total phenol and tannin contents were higher than in K-7, the susceptible variety. Peroxidase activity, polyphenol oxidose and phenyl alamine ammomia lyase (PAL) and total phenol content were reduced in the blast infected plants.

The pathogen can invade the host through stomatal opening or through direct entry by riereing the epidermal cells. The resistant varieties exhibit higher cytoplasmic granulation than the susceptible varieties (Madhukeshwar, 1990, 1997b).

Genetic basis of resistance

Seetharam and Ravikumar (1993) worked out the genetics of blast resistance by adopting line x taster analysis approach. The indication was that there was on operation of additive gene action for finger blast. However, five generation mean analysis revealed non-additive gene action for nect and finger blast they showed that for neck blast, both additive and dominance gene effects were significant with the

predominance of dominance gene effects. Among epistemic gene effects, additive x additive gene effects were important. All the three types, viz., additive, dominance, additive x additive and dominance x dominance gene effects were found important in respect of finger blast. In the case of GE-447 X GE 156 only additive and additive x additive gene effects were significant. The estimates of narrow sense heritability neck blast was low and medium for finger blast suggesting additive gene effects were not important for the expression of these characters. Further, Ravikumar and Seetharam (1994) observed moderate to high genetic variability for neck and finger blast in populations. These characters – neck and finger blast – showed high heritability and high genetic advanced, which indicated the role of additive gene action.

The phenotypic and genotypic coefficient of variation was large for finger and neck blast. Both additive and non-additive gene effects played significant role in the expression of blast disease. High genetic source manifested by the disease suggested the scope for the improvement of this character with simple selection (Byregowda et al., 1997 and 1999a).

Sources of resistance to blast disease

Evidently, the blast is a very severe disease and more often than not, it becomes destructive causing heavy losses the crop to the extent of 50% and above. This signifies the fact that resistance breeding commands top priority. But the important thing is the availability of variation at the population levels.

The first ever observation on the existence of variation for this disease at the population level was by Thomas (1941). Everscince, more exhaustive work has been done by several workers (please refer to the publication of the Hand Book on: “Disease of Finger Millet” by Anil kumar, Mautur and Madhukeshwar, 2003" of the project coordinating cell of AICSMIP of ICAR, headquartered at university of agricultural Sciences, GKVK, Bangalore. This exhaustive review identified many accessions having resistance potential to this disease and that they were summarized for ready reference.

Sl. No.	Varieties	Reference
1	IE-120	Anonymous, 1970
2	PR.722	Deshker et al., 1973
3	TAH-91-1, TAH-8	Poll and Nema, 1978
4	APV-27	Rath and Swain, 1978
5	KYO.127	Moelinsuki *et al.*, 1978
6	Rampur Local	Tamong, 1982
7	TE-882, IE 1941, U.47, U-10, U.45, GE.304, GE.713	Seetaram and Viswanath, 1982
8	IE 203, IE 207, E-215	Singh and Gupta, 1983
9	IE Nos: 5, 27, 28, 765, 416, 596, 708	Guha, 1983
10	Nirmal	Gupta and Singh, 1983
11	KM.31	Gpta and singh, 1985
12	IE.1012, HPB 96-11, MR.1, MR2, MR3	Viswanath *et al.*, 1986
13	Kakaeri	Patnaik *et al.*, 1987
14	Co12	Sundareshan, 1988
15	P-248, P.277, IE.882, IE.891, T-249, 410, GE.746	Sharma *et al.*, 1988
16	GE – Nos. 1273, 1276, 1505, 1796	Lucy channamma, 1987
17	GE Nos. 75, 669, 866, 1309, 1407, 1409	Ravikumar *et al.* 1990
18	GE. 2362, GE.232M GE.769	Pau, 1991
19	GE.1170, GE.1309, PR.1158	Smashekar *et al.*, 1992
20	VL.149	Devandra mohan, 1993
21	GE.5016, GE 6002	Shrehan and Baniya, 1993
22	GE.411, IE. 3207	Naik *et al.*, 1993
23	TNAU 551	Ramaswamy, 1995
24	286 accessions in Germplasm	Ramakrishna, 1996
25	36 accessions in Germplasm	Viswanath *et al.*, 1997
26	GE. Nos. 406, 669, 705, 1293, 1309, 1409, 1546, 3510	Gupta and Prasad
27	IE-2897, 2912, 2885	Fakrudin *et al.*, 2000
28	39 CULTURES FROM GERMPLASM	Somappa, 2000
29	AKE . 1033, MR.2	Rajanna *et al.*, 2000
30	GE.2400, 4913, 4914, 4915	Mantur *et al.*, 2001a
31	GPU-28, GPU.45, GPU.48	Mantur *et al.* 2001b
32	GE.669, 676, 632	Sunil, 2002
33	GE.Nos. 250, 261, 263, 320, 338, 344, 352, 416, 357, 371, 383, 396, 398, 400, 406, 409	Santhakumar, 2002
34	MR.1, GPU-56, GPU.58, VL.321	Ramappa *et al.*, 2002b

Source: Anilkumar *et al.* (2003), AICSMIP (ICAR), UAS, Bangalore

Further, Mantur *et al.* (2002) evaluated 18 lines over 3 season from 1996 to 1999 at UAS, Bangalore and found genotypes IE-18 and GPU-28 were free from neck blast and GPU 26, VL.149, VL.253 were resistant to blast. The neck blast incidence in MR.1 was 1.33% and in GPU.28 it was 2.0%, while it was 30% in PR.202 during kharif 2000 in Mandya and Mysore districts of Karnataka (Ramappa et al., 2002a). Sanath kumar et al. (2002b) studied an early event of infection and found there was a significant reduction in the length of germ tube, appresarial development, size of the reisions and numbr of spares per resion the resistant genotypes comparable to suscepliable ones. Kishore Sherenan and Bimal Bamia (1993) listed PR.202, GE. 5016, GE.6002 and rillicaro as resistant in Nepal. Elober and Adipala (1993)found a variety Ekama to be less susceptible to blast in Uganda.

In a study on variability for graincfield and related traits in 196 germplasm accessions in Malawi, variation in the incidence of finger blast among them was significant (Mnyenyembe and Gupta, 1998).

In retrospect, about 688 entries in the recording table are a few accessions mentioned in the following paragraph are a promising sources to exploit through appropriate breeding strategies to insulate the varieties against the ravages of the blast disease.

Disease control

Anilkumar *et al.* (2003) made an excellent review of various chemical control methods to combat blast disease in ragi and summarized.

Bio control of blast disease

Various plant extracts seemed to have an effect in controlling blast disease. Among them, the cold extract from *prosophis julifera* (10% concentration) was found to inhibit the mycelia growth to the extent of 93.5% spare germination was reduced by 80.2%. the plant treated with this extract, recorded the lowest level of incidence of neck and finger blast and higher grain yield of 2364 kg/ha was obtained as against 1804 kg/ha from untreated plot. In addition, certain plant products, especially of neem origin like Vijaya neem and econeem were tried during kharif 20091 under AICSIMP, Bangalore and they were found effective (Anon., 2001). Further, two sprays of Saff (0.2%)

first spray at 50% flowering and second at 10 days later was found effective in increasing the yield by reducing the inpact of the disease incidence.

Neck and finger blast incidences was least where *Gleoctodium virus* was used and I was next to Bavistin treatment in its effect on the disease control. Sitther and Gananamanickam (1996) tested six strains of fluorescent *pselldomanods*, which belonged to *P. fluoreseens* and *P. pretida* for their ability to ihibit the blast fungus. These bacterial strains inhitted the furgal growth in dual plate assays in the laboratory and rduced ragi blast severity in the field. Leaf and neckblast incidences were reduced by 45.3% to 4.2% and 24.3% to 54.9% respectively, in the moderately resistant variety co.7 and 59.1.1 to 72% ad 23.3 to 63.3% respectively in the susceptible variety PR 202. However, *P. fluoreseence* strains 7-14 were most effective amongst the bacterial treatments.

Overall, a good reappraisal of the bacterial treatments. Disease in ragi from the available literature has been made by Anilkumar, Mantur and Madhukeshwara of AICSMIP, Bangalore and summarized:

Fungicidal/ bio control agents effective against ragi blast.

Sl. No.	Fungicides and other agents	Reference
1	Bordeaux / copper oxychloride	Raju and Rao. 1941
2	Cereson lime dust/ Dithane Z. 78	Shanmugam et al., 1962
3	Aurcofungin	Sundaran, 1969
4	Hinasan / brestonol	Keshi and Mohanty, 1970
5	Benlate	Deshkar et al., 1976
6	Miltox	Shivaprakashan et al., 1976
7	Panoctine – R (Seed dressing)	Ranganathiah, 1978
8	Breston	Mohanty and Mahaptra
9	Mancozes	Channamma et al., 1979
10	Captafol	Sudarshan Rao et al., 1982
11	Bavistin	Sudarshann Rao and Channamma, 1983.
12	Bletox	Pau, 1984
13	Ibp	Mohan and Jayarajan, 1986
14	Allitin	Jagannathan and Narasimahn, 1988
15	Kitazin, saprol	Rajasekhar et al., 1989
16	Topsin – m	Arunkumar and Snigh, 1995
17	Prosaphis juliflora extract (10%)	Ramaswamy, 1995
18	*P. flusescens*	Sitther and Gnanamamkam 1996
19	Tricyclazole	Viswanath et al., 1997
20	Chborothalonil	Singh et al., 1997
21	*Gleocladium virens*	Somappa, 1999
22	Neem products	Anonymous, 2001
23	Saff (0.2%)	Ramappa et al., 2002c.

Disease management options are aplenty as could be seen from the list, nevertheless, use of disease resistant varieties is the best option. However, Trivedi (2001), who studied the management aspects of various diseases in plants including blast on ragi suggested the integrated system consisting of resistant varieties, seed treatment with thisam or mancozen, reduction of nitrogenus fertilizers by 25% and finally spraying of the crop with mancozeb.

On Farm Adaptive Research (OFAR)

On Farm Adaptive Research trials were organized in Karnataka (India), during 2000-01 and 2001-02 under the National Agricultural Technology Project to demonstrate blast management in ragi on a field scale. The components of the technology were the use blast resistant variety GPU .28 combined with seed treatment with carbendozim. All other crop production management practices were as per the farmers own method of cultivation. The results were as **tonisling** by way of increased yield ranging from 50 to 100% over the fields outside the project area (Madhukeshwara et al., 2002b). the outcome was, indeed, impressive to the participating farmers with a potential to have cascading effect.

Seedling and leaf blight

This disease is caused by *Helminthasporium nodulosum* Subramanian (1971) transferred this genus to *Drech slera* and thus renamed it *Drechslesa nodulosa*. It is next to blast in severity on ragi and hence claims importance. It is most widely distributed in almost all the ragi growing parts of the world such as India (Coleman, 1920), Uganda (Sydow, 1927), east Africa (Castellain, 1938), USA and Philippines (Butler, 1918), etc. in India, it is found in most parts of the country (Govidnu, 1982; Mitra, 1931; Thomas, 1940 and Naraim et al. 1975). Although it was not considered a severe disease, however, in combination with *Fusarium culmorum* and virus, it occujrred in a devastating epiply to tic form in south India way back in 1965-66 (Govindu and Shivanandappa, 1967) and caused heavy loss to the crop.

All the parts of the plant are prone to attack the plant, especially at the seedling stage. It is seedborne and thus seedlings are after affected and die before they emerged. Leaf lesions appear in plenty and they are small, oval, brown spots, which gradually elongate parallel to the main axis of the leaf. Whereas the lesions on the leaf sheath appears much larger in size and are dark-brown in colour. They commonly occur at the junction of the leaf blade and leaf sheath. The symptoms o the leaf sheaths, culms and internodes usually appear as large, irregular, dark-brown to nearly black blotches. Under severe infection, the entire mode and internode, especially at the basal stem position become involved. In addition, blackening of the collar region in most of the affected plants was observed during epiphytolic form the entire earhead in the infected plant becomes dry. The grains may not develop fully and thus they become shriveled leading ultimately to heavy yield loss.

Shankar and Shetty (1989a) observed the disease symptoms on glumes, palea, lemma and seeds from hard dough stage onwards. However, the concentration of fungal spores was maximum on leaf surface at flowering stage (Shankar and Shetty, 1989b).

Several species of *Helminthosporium* were reported to occur on finger millet. McRoe (1932) and Mehta (1934) observed the occurrence of *H. leueostylum*, which was less severe than *H. nodylosum*. There more species were reported such as *H. holmii, H. tetramera* and *H. rostratum* (Shigh and Misra, 1978; Vasudeva, 1960, Lele and Dhanraj (1966).

Luttsell (1956) first reported *cochliobolus kusanoi* Nisikado as the perfect stage of *H. nodulosum.* After realizing variation in the conidial stage of *C. Kusanoi* from that of *H. nodulosum*, be described it as a new species stomata or directly through the epidermis. The long conidiophores are septate, dark-brown at the base and sub-hayline at the tip and measure 80-250 x 5.7 M. Thick walled 3-10 septate conidia are borne singly in succession at the lip of the conidionnore. They are obclavate to cylindrical, tapering at both the ends with a hilum at the base measuring 40-110 x 11-21 M. Thdy germinate by germ tubes

from the end cells, either suigly or one after another. As many as 11 conidia may be format on one conidiphore. They are thick walled and light russet green in colour.

The pathogen produced sexual fruiting bodies in culture, which possess cylindrical beaks, black in colour and spherical in shape. These ascocasps (perithecia) measure 276-414 in diameter, the beaks are 97-262m in length and 55-83 m in breath. The asci are short and straight with 1-8 ascosposes whose apex is rounded. They measure 120-193 M x 14 -17 M. asci are emedded in presudoparaphyses. The ascosposes are spirally coiled within the ascus. They are hyaline, filiform and 11- septate. (Pande and Shukla, 1977).

The pathogen is known to infect *Eleusine indica, Dactglocacmium aegypticum, Setaria indica, Ecluinochloa frumentaceac, panicum miliaceum*, pearl millet, sorghum and sugarcane (Mc Rae, 1932, Mitra, 1931, Mitra and Mehta, 1934), wheat, barley and Oats (Thomas, 1940, 1941).

The temperature range for infection of *H. nodulaion* was between 10'C to 37'C with an optimum at 30'C to 32'C (mitra and Mehta, 1934). It requires more than 95% RH for good spore germination. More than 80% spares fenetrate the host within 4 hours of inoculation and they take 24 hours to express. The spares carried on the seeds remain viable for one year (Narasimhan, 1933). Vidyasekharan (1971) studied the survival of the pathogen in the soil for and found in at it 18 months. Reddy and Luke (1979) developed technique to maintain virulence of the pathogen by baiting the fungus on ragi eulms.

Most of the present day varieties of ragi are relatively less susceptible. Despite this, the damage by the pathogen to the seedlings in the nursery under warm, humid conditions or to the developing seeds in the ear are considerable.

Venkatakrishnaiah (1935) suggested seed dressing with Fermate or Agroson in addition to cereson. Agsoson was found to be more effective (Grewal and Pal, 1965). Capton was found to be the best followed by Erestan and Duter (Hegde and Shivanadappa, 1968). Morestan and rhizome extract of Canna plant extracts inhibited the spore germination. (Ahmed and Sutha, 1973). Treatment of seeds with panoctine plus (Guazatine + imazolit) was not only effective against seed borne *H. noderlosum* and also increased germination (Ranganathiah, 1978).

Jagannathan and Narasimhan (1988) evaluated *in vitso* 66 extracts of plant products and found that a synthetic product from garlic oil or neem oil, neem leaf, parthenium leaf, turmeric rhizome and garlic bulls was effective in inhibiting spore germination and mycehial growth. Application of cumin (0.3%), once at flowering and again after 15 days later helped in controlling the disease (Patra, 1996).

Coleman (1920) observed differences among varieties about the level of resistance to seedling blight. According to leim, the varieties with green glumes were more suscep[tible than those with purple glumes. Govidndu *et al*. (1970) evaluated 806 varieties from India, Africa and USA under field conditions and found as many as 139 lines were resistant. The least incidence was found with two progemies, 7-74-2-1 and 5-25-3-1 by same Gowda and Viswanath (1986). Six Germplasm lines; GE Nos. 130, 250, 404, 510, 676 and 1423 were found resistant. Somasekahar et al. (1988) screened 25 genotypes at Bangalore and found that TNAU-332, PR. 902 and GE.130 showed partial resistance. Govindu and Keshavamurthy (1976) listed varieties, which have combined multiple resistace to blast, foot rot and leaf height.

Foot Rot.(*Sclerotium rolfsii*)

Foot rot on ragi is caused was first reported in India by Coleman (1920) and from Sri Lanka by Park in 1930. In India, it is present in Andhrapradesh, Tamil Nadu, Karnataka and Orissa (Mc Rao, 1928; Sundaram, 1933; Narain, 1972) Small (1925) reported from Uganda. Although, it was prevalent on all varieties, it was of little economic importance (Elobu and Adipara, 1993). Loss of crop on account of foot in Rampur, Nepal was said to be around 50%.

The disease is caused by *Selerotium Rolfsii* in imperfect stage and in Basidial stage, it is called *Pellicularia rolfri*.

The basal portion of the plant initially appears water soaked due to infection by the pathogen. Later, this portion turn brown and then becomes dark-brown and the affected portion of the stem shrinks. White cotto nycelial growth occur profusely in this area. Roundish small white relvety grain like structures appear in the fungal matrix. These grow, attain the size of mustard seeds and turn brown. They are the selerotial bodies. Mean while, the leaves loose their luster, drop and dry, ultimately leading to the death of the plant.

Sandy loamy soils favoured the disease incidence and the pathogen survived better at low moistures levels (Sujatha, 1991). The disease incidence is more during warm and dry months. Under Bangalore condition, the disease incidence was more in February- April months (Viswanath and Channamma, 1987). Further, selerotium – nematode complex was also reported (Govindu and Swamy, 1966). Maintanance of good drainage helps to check the disease impact.

The fungicide PCNB reduced the severity upto 65% quintozene was also found to be good to control the disease (Govindu et al., 1966). Channamma et al. found Duter, a tin compared and vitavax were more effective and better than Brassicol in controlling the disease.

To identify the source of resistance to *S. rolfsii* and nematode disease complex, Govindu and Swamy (1977) screened 884 lines from the Germplasm and found 322 accessions were resistant, 239 intermediate and 323 susceptible. Sannegowda and Pandurangegowda (1984) found many of the varieties like Indaf -3, Inaf-78 and Indaf-9 were less prone to disease. Out of 21 accessions tried over three years, Jain et al. (1994) found PPR. 1735 to have stable resistance. Batra and Tamong (1983) reported Rampur local from Nepal was highly resistant.

Smut disease

Smut disease is caused by *Melanoprichium elesinis*. It occurs at random in the earhead. Diseased grains are transformed into galls or bullet bodies, which are six to seven times more than the normal size of the grain. The affected grains are single, and some items appear in groups in the form of patches of varying sizes. The other type of symptom was that the infloresance remained extremely reduced in size containing only surivelled groups. There was complete absence of development of spike or spirelets including glumes, which were replaced by greenish, globose to elongated sac-like structured filled with sooty telio[spores (Vijayaraghavan and Patil kulkarni, 1977).

Another type of bymptom was that the sori were found to occur around the stalk of the mainrachis of the infloresceuce in the form of galls, scattered or colessed with each other containing mass of teliospores and sometimes, there were abundance of small and elongated sac-like small sori sesembling phyllody instead of developing into normal grains. Colour of the fully developed sori were brown of chocolate brown and on the white grained varieties, the matures sori were dull-white or bluff coloured.

The disease was first observed in erstwhile Mysore state in India (Coleman, 1920). In Maharashtra, it occurred around that time at Malkapur near Kolhapur in erstwhile Bombay state. It was also reported from Tanzanai. Sydow (1929) described this disease in *Elensine indica* from Nankang, China as a new species.

The pathogen was first named as *ustilago eleusinis* by Kulakurni. But later, it was transferred to the genus *Melamospsichium* and the renamd it as *M. eleusinis*. The spores are flbose. The apispose is distinctly hitted with a rough surface.

Infection was air brone and floral infection accurred when sporidial suspension was found over the earhead at the time of emergence of the head. It was also reported that infection occurs when the soil was inoculated with teliospores at the time of the plants nearing heading stage. The disease was also reproduct when the telispore suspension was inoculated into young inflorescence yet in sheath.

Spore germination was low, erratic and irregular, maximum germination occurred with in 24 hours of incubation of freshly

collected spores (Ganapathi, 1971). The optimum temperature for spore germination was 25'C. There were two types of germination:

- *Mycellial type*: Germination first started as a small hyaline, straight or sent tube and gradullay elongated into aslender hypha.
- *In sporidial type*, Germination starts with the appearance of a small hyaline germtube, which gradually elongated and became promyeellium. Two transeverse septa were formed dividing the promyellium into 3 to 4 cells. Pronycellial gave rise to lateral sporidia or short branches near the septa. The sporidia were avate or cylindrical rarely spindle shaped. Uninucleate and thinwalled.

Vijayaraghaven and Kulkarni (1977)suspected the presence of physiological specialization of the fungus; but no proof was produced.

Teliospores were studies by Khanna and Payak (1971) through electron microscopy. This revealed that the suface was densely echinulate and showed some type of out growths. The large sized conical projections were sharply pointed. In addition, numerous small out growths called 'spinulae' or 'papillac' were also present.

As per control methods, it was felt that since the couidia of the pathogen were airborne and infection being resisted to a few flowers, chemical control method was non-viable. Yet Hiremath et al. (1985) evaluated invitso a few fungicides and found Bavistin was highly effective. However, least infection was noticed when Difolatan was sprayed at pancle initiation stage followed by a mancozeb spray at flowering stage.

Since this disease is not that distructive as blast, and also low blue crop, resistant breeding is a desirable option. Sannegowda and Viswanath (1986) screened 139 lines during kharif and summer during 1985-86, the maximum incidence of the disease in kharif was 20.38% and the same was 46.16% in summer. However, 4 entries were found to have stable resistance during both the season. Further, a set of 79 accessions were screened during 1990-91 under the AICSMIP at

Bangalore and found that the disease incidence in general was 80% in certain accessions. Despite that, a few genotypes such as Ge. No. 2700, 3858, 3061, 3075, 3093, 3542 and 4146 were found resistant.

Mantur *et al*. (1996) screened 94 genotypes over two seasons at Bangalore and found that the genotypes sprayed with sporidial suspension from 10 days old cultures at flowering, the incidence of the disease ranged from 0 to 62.4%. yet accessions like GE. Nos. 1309, 2856, 4454 and GPU.25 and GPU.26 were free from smut infection.

Apparently, there are some good sources of resistance in the populations and if they are properly dovetailed into breeding strategies, a good number of resistant varieties combined with desirable agronomic features could be evolved.

Downy Mildew Disease

Downy Mildew disease is relatively a severe one on ragi. But its occurrence is sporadic (Anilkumar *et al*., 2003). This disease was first reported by Venkatarayan (1946) in erstwhile Mysore state in India. Ananthanarayana (1963) mentioned its presence in Pune in Maharashtra. Some confusions existed about its nomendatural confusions and it was finally cleared by Thirumalachar and Narasimhan (1949) who identified the pathogen as *Sclerospora macrosposa*, a name originally proposed by Saccardo (1890).

The Pathogen has been reported from USA, Japan, Italy, Australia, France, Canada, Peru, erstwhile USSR, China, Germany, South Africa, Maritius, Bulgaria, Mexico, Pakisthan and erstwhile Yugoslovia on various hosts. Safeeulla (1970a) made a detailed study of downy mildew on sorghum, pearl millet and ragi. Govindu et al. (1970) gave a report on the then status of downy mildew disease on ragi in Karnataka, India.

Sclerospora macraspora has wise range of hosts in the family gramineac amounting to as many as 141 hosts. Detailed review of the genus sclerophthora was made by Safeeulla and Shaw (1962), Payak et al. (1970) and Raghavendra (1974) on various aspects of downy mildew.

Symptoms of the disease are that the infected plants are generally stunted in growth with shortened internodes, crowded leaves giving abusloy appearance and are after pale yellow and transluscent sports are seen on leaves. The most striking features of the disease is either completely or partially, proliferated spikelets into leafy structures (Safeeulla, 1976). Mycelium is seen in the emlsryo and endosperm in the infected seeds. On germination, mycelium spreads to meristamatic tissued leaves, roots, spikes, and seeds are found to have significantly higher amount of total nitrogen than their healty counterparts. Diseased plant tissus contain Cystin and tryptophan which are totally absent in the healty tissues. Further, aspargin, glutamic acid, fruetose, glucose and sucrose contents are also more. However, the Indole Acetic acid content in mildew spikes is less than in healthy spikes. Chlorophyll contents a, b and total chlorophyll is significantly lets in the affected leaves (Safeeulla, 1976).

The life cycle of the pathogen was described by Safeeulla (1955). The white Colony growth is generally not seen in the diseased plants. The first sporangium is formed at the apex, which is followed by the development of sporangia in lateral positions. These are lemon shaped with a prominent apical papilla and pedical. They germinate and liberate many unequally, biflagellate zoospores. The optimum temperatue for germination is 22’C to 25’C (Safeeulla, 1976). Maximum germination occurs at pH 6.5, which is also the same for zoospore germination. Sporangia germinate with in 3 hours. Light seems to have very little effect on sporangial germination (Raghavendra and Safeeulla, 1971).

Mycelium is multinucleate and upto 48 nuclei have been observed in the sporangia. Each treatment in the zoospare contains a nucleus. The zoospores are pyriform, spherical or irregular. They germiuate by germ line with the formation of appresorium. Eight chromosomes are recorded in each zoospore (Safeeulla, 1976).

Oogonia develop as swellings of the mycelium both in the apical and interealary positons and contain a number of nuclei. One of the latoral branches from the mycelium develops into an antheridium in the vicinity of oogonium. Mostly one or two autheridia are associated with each oogonium. The nuclei in the autheridia and oogonia divide simultaneously. About 40-100 nuclei are seen in each oogonium. In the mature antheridium 16-24 nuclei are observed. At a later stage, nuclei migrate to the peripheral region and a dense protoplasm mass is commonly seen in the ooplasm with a single nucleus. The nuclei of the periplasm degenerate and helps develop oospore wall. The receptive papilla enters the antheridium before the antheridial tube penetrates oogonium and discharges its content in to the ooplasm.

Eight to 9 nuclei have been observed in the fertilization tube jand the remaining autheridial nuclei degenerate. The zygote divides repeatedly and give size to 30 to 35 nuclei. The oosore develops a thickwall and the matured oospore has three wall layers. The outer most has mjultimudeate sporangium, which liberates several zoospores (Safeeulla, 1970b, 1976).

Zoospores are released at 26-30'C and they infect young ragi seedlings. The pathogen is internally seed borne (Safeeulla and Raghavendra, 1971, 1978), it has a wide host range and thus disease development becomes easy. The infected grass hosts survive much longer than usual period thus aiding perpetuation and ispersal of the pathogen.

Venkataraman (1956) observed green ear disease to be more jsevere in transplanted ragi. Similar observations were also made by Govindu et al. (1970). While it has a wide range of hosts, the most important economic plants known to get affected by the downy mildew disease are oats (Noble, 1934), barley (Whitehead, 1955), rice (yamada, 1911), pearl millet (Safeeulla, 1976), sugarcane (Staindal and Smith, 1952), sorghum (whitehead, 1958), wheat (Severini, 1913), Corn (Cugini and Traverso, 1902) and Aoon.

Systematic infection occurs at seedling stage. Seed treatment with chemicals, apson and Ridomil MZ would check infection (Anilkumar

et al., 2003). Howver, alternative method to control the disease is by breeding resistant variaties. At the university of Mysore (Karnataka) Safeeulla (1976) tested 360 varieties of ragi and found as many as j175 varieties did not get infection, while the rest is the test plot has infection ranging from 58 to 100% (Safeeulla, 1976).

Cerconspora leaf spot

This disease is caused by *Cercospora Elusinid*. It is an important disease on ragi. It is very much found in Himalayan foot hills and mid hills of Nepal. It is reported to be one of the most destiuctive disease in ragi in Zambia (Mugange, 1995). Munjal (1961) collected the material from naintal in Himachal Pradesh, India and after studying described it as a new species, *Cercospora elusinis*.

If the disease occurred immediately after heading, could reduce the yield upto 40% and 1000 grain weight by 21.0% (pradganag, 1994). When the disease incidence is around 25%.

Plant diseases

Small millets including finger millet /ragi have been the sources of staple food crops in the semi-arid and arid regions of the world. Ragi occupies a share of 50% of the total area of 4.8 million / ha under small millets in India. Besides, Nepal, Sri Lanka, Japan, Zimbaway, Uganda, Ethiohpia, Kenya, Tanzania, Zambia and so on in Africa also grow this crop.

Comparatively, finger millet is less prone to diseases. Nevertheless, there are as many as 25 fungal, 4 viral, 5 bacterial and 6 nematode diseases infect the crop causing variable degree of crop losses. But more destructive one is blast disease caused by *Magnportha grisae* and the annual crop loss by this disease is estimated at 25% in India. The diseases of finger millet / ragi as a whole were dealt with in detail by Anil Kumar and his colleagues in 2003 at AICSMIP (ICAR), located at University of Agricultural Sciences, Bangalore and basically it has formed the main source of material for this book on plant diseases, which is acknowledged most sincerely.

Fungal diseases

Blast

Out of 25 fungal diseases, blast caused by *Magnaportha griseae* has become most destructive causing heavy crop losses. Besides India, it is also a serious disease in Nepal and many African countries where ragi is being cultivated. The disease was first reported in Tamil Nadu and subsequently from erstwhile state of Mysore (now Karnataka) (Mc Rae, 1920 and Venkatarayan, 1937). The crop losses inflicted by this disease were estimated at 100% in Nepal (Batsa and Tawang, 1983) and 25.46% at the lower elevations (160 meters) of Himalayan region. Ramappa (2002) reported up to 50% loss due to neck blast and 70% due to finger blast during 2000 in Mandya and Mysore districts of Karnataka.

Disease affects the crop at all stages of crop growth, beginning from seedling to grain formation stages. In the nursery, lesions are formed on the leaves, which are spindle shaped of varying sizes. The spores were at first greyish-green in the centre with yellowish margins. Later centre position turns whitish and gradually disintegrates. To begin with, the lesions are isolated, but might coalesce soon, covering extensive areas.

Adult plants from transplanted or broad cast or drilled crop showed infected leaves beyond lesions droop and break. When the infection occurs on the stem, nodal region becomes black and it extends upto 50-100 mm on both sides of nodes and later penetrate into the stem. The neck region becomes discoloured and shrinks in size to a length of one or two inches. This makes the neck become weaker and makes the earhead hang down or break from the stalk. This condition of the neck is refered to as ***"rotten neck".*** Earheads, especially the rachis, are attacked by the disease resulting in a few shrivelled grains. The most damaging phase of the disease was when it infects the neck region. Two or few inches of neck region immediately below the head turned initially brown and then turned black. Olive-green growth of the fungus was noticed on this blackened area.

When the pathogen attacked fingers, the infection was usually from apical region downwards. At times, entire or nearly entire length and breadth of the earhead would be covered by the disease resulting in no seed development or producing few shrivelled grains with blackish colour.

Though the fungus was known earlier as *Pyricularia orizae or Ceretosphaeria grisea*, finally, it was named as *Magnaportha grisae* (Yageshi and Udagawa, 1978).

Structurally, its hypha is hyaline and septate and brown in colour. Under high humid condition, large number of conidia were produced giving dirty-brown colour to the lesions. Generally, the growth of the fungus was more on the upper surface. However, the conidiophores would emerge through stomatal opening or directly from the epidermal layer. They were simple, septate and the basal portion relatively darker, and cell would germinate and produce germ tubes. The pathogen produced plenty of dark coloured chlamydospores in culture (Venkatarayan, 1937).

The pathogen grew luxuriantly on oat meal, potato dextrose, bean meal and agar. Among synthetic media, Richard's medium was the best. Maximum growth was found at P^H 6.9 and temperature at 30°C. However, the Somalian strain required 12 to 35°C and the optimum being 25-31°C (Mohamed, 1980). Glycogen and sucrose produced maximum growth amongst carbon sources. Asparagin was the best nitrogen source followed by glutamic acid, tryptophan, ammonium nitrate, potassium nitrate and so on. Differences in lipids and fatty acid patterns showed that rice and finger millet isolates were closer to each other relative to pearl millet (Kumar *et al.,* 1997b). Zeigler (1998) opined that recombination might have taken place between isolates from rice and finger millet in Himalayan region, where the two hosts coexisted for centuries. DNA polymorphism of isolates showed that they were genetically isolated and distinctly different host-limited groups. Cross-inoculation tests revealed that they were host-specific.

Isolates of *M. grisae* were able to produce micro conidium and were heterogenous in their sexuality in which some were hermophroditic, some male fertile and some female fertile (Kato *et al*., 1978). Yageshi (1977) noticed the presence of abnormal ascospores in crosses between strains pathogenic to rice and finger millet. In terms of virulence of the isolates collected from different parts of India, when tested against 6 resistant varieties, Veena Hegade (1996) found that the most virulent isolate was the one collected from Kanke in Bihar, followed by those from Anakapalle (A.P.), Bangalore, Berhanpur (Odisha) and Coimbatore (Tamil Nadu).

The type of toxin found in the pathogen was Pyriculol and there were six types, of which Pyrichalasin-H was important (Swamy Rao, 1966, Sanathkumar *et al*., 2002a). Yagashi and Asaga (1981) studied the inheritance of pathogenicity in crosses between *Pyricularia orizae* and *Pyricularia grisae* and concluded that the opportunity for gene flow between rice and finger millet isolates on a common host was unlikely.

Collateral Hosts

The host-range studies in Maharashtra (India) had found that an isolate from ragi also infected barley and wheat. Rice and ragi pathogens were not cross-inoculable (Totman, 1994). However, Ramasamy (1935) observed that *Brachiaria mutica* and *Panicum repens* were collateral hosts of ragi blast. It also readily infected *Setaria italica*, *Eleusine indica, Lolium multiforum, Festuca elator,* wheat, barley, oats, maize and hybrid napier grass.

Cultural and nutritional effects on the incidence of the disease

Investigations at Similiguda (Odisha) revealed that incidence was more in direct-seeded ragi crop. Perhaps, it could have been due to overcrowded plants (Mishra *et al*., 1985). Besides, increased application of nitrogen aggravated the disease at Payur (Tamil Nadu). There was no significant reduction with increased dosage of potash.

Losses due to blast

Amongst others, blast disease was the most destructive one (Mc Rae 1922). Approximate estimate of the crop loss reported by Venkatarayan (1947) was found to be between 80-90% in erstwhile Mysore State in India. Whereas, loss in Uganda (Africa) was reported to be around 10% (Anon., 1959). Ultimate loss in grain yield was accounted for by the reduction in number and weight of the grain and spikelet sterility (Rath and Misra, 1975). Further, Pall (1977) reported the death of affected seedlings, damage to foliage, reduced plant growth and tillering, panicle length, grain number and grain weight were the other causes. Batsa and Tawang (1983) reported 100% crop loss in Nepal. In India, it was found to be a regular feature for the disease to strike and the average yield loss was around 28% (Seetharam and Viswanath, 1983). However, the losses accounted for by leaf, neck and finger blasts were 20.6%, 36.89% and 42.5%, respectively. Variety-wise losses were reported at 33.15% for VL.204, 34.30% for *Purna,* 9.9% for VL.101 and 4.76% for PR.722. (Sharma *et al.,* 1988). Evidently, there was a varietal variation in respect of susceptibility to blast disease.

Ekwamil (1991) observed significant reduction in grain yield in Uganda due to decreased spikelet length, grain weight and number of grains per earhead. In a two year trial, it was found that variety BM.1 suffered 54.7% yield loss, while BA.2 with 51.5% loss. The loss in fodder yield was 42.6% and 5%, respectively (Haider, 1992). Viswanath and Channamma (1989) raised the crop year round at fortnightly intervals and found that neck blast incidence was maximum in August – sown crop at Bangalore. Whereas in Almora, sub-Himalayan region, the May-sown crop was worst hit.

Pall (1988) described the role of seed borne inoculums on blast incidence and severity. The infection immediately after flowering resulted in 76.82% and 70.14% reduction in grain yield and 1000 grain weight. However, it was only 50% reduction in both grain yield and 1000 grain weight when the infection occurred at milk stage of the grain. Ramappa (2000e) showed only 5% reduction in both grain yield and 1000 grain weight.

Disease control

Anilkumar *et al*., (2003) had made an excellent review of chemical control methods to combat the disease and summarized in the following table:

Fungicides

Sl. No.		Reference
1	Bordeux / Copper oxychloride.	Raju and Rao, 1941
2	Cereson lime dust / Dithane Z.78	Shanmugam *et al*., 1962
3	Aurofungin	Sundaram, 1969
4	Hinasan / Brestonol	Keshi and Mohanty, 1970
5	Benlate	Deshikar *et al*., 1976
6	Miltox	Shivaprakasham *et al*., 1976
7	Panoctine – R (Seed dressing)	Ranganathiah, 1978
8	Breston	Mohanty and Mahopatra
9	Mancozeb	Channamma *et al*., 1983
10	Captafol	Sudarshan *et al*., 1982
11	Bavistin	Sudarshan Rao and Channamma, 1983
12	Blitex	Pall, 1984
13	IBP	Mohan and Jayarajan, 1986.
14	Allitin	Jagannathan and Narasimhan, 1988
15	Kitazin, Saprol	Rajasekhar *et al*., 1989
16	Topsin – M	Arunkumar and Singh, 1995

Bio-control of blast disease

Various plant extracts seemed to have an effect on controlling blast disease. Among them cold extract from *Prosophis julifera* (10% concentration) was found to inhibit the mycelial growth to the extent of 93.5%. Spore germination was reduced by 80.2%. Plants treated with this extract recorded the lowest level of incidence of neck and finger blasts and gave higher grain yield of 2.37 t/ha as against 1.80 t/ha from untreated plots. Additionally, neem products like Vijaya neem and Econeem were found effective during Kharif 2001 at Bangalore. Further, two sprays of Saff (0.2%), first spray at 50% flowering and second at 10 days later was found effective.

Neck and finger blast incidence was the least when *Gleoctodium viren* was used and it was better than Bavistin treatment. Sitther and Gnanamanickam (1996) tried six strains of fluorescent psuedomonads, which belonged to *Psudomonas fluroscens*. and *P. pretida* for their ability to inhibit the blast fungus. These bacterial strains inhibited the fungal growth in dual plate assays in the laboratory and reduced blast severity in ragi in the field. Leaf and neck blasts incidences were reduced by 45.3% to 65.2% and 24.3 to 54.9%, respectively in the moderately resistant variety CO.7 and 59.1 to 72% and 23.3 to 63.3%, respectively, in the susceptible variety PR.202. However, *P. fluorescence* strains 7-14 were most effective amongst the bacterial treatments.

Several disease management options have been available. Nevertheless, the use of disease resistant varieties is the best option. Trivedi (2001) suggested the integrated system of control, which included resistant varieties, seed treatment with thiram or moncozeb, reduction in the application of nitrogen fertilizers by 25% and finally spraying of the crop with moncozeb.

Machanism of resistance to blast

a) Physical basis

Anatomical studies revealed that epidermis-cum – cuticle thickness were significantly higher in the leaves of the resistant genotypes than in the susceptible ones. Stomatal frequency per mm^2 and size were significantly less than in highly susceptible varieties (Santhakumar *et al*., 2002b). However, Jain *et al*. (2002) showed that leaf area, leaf angle, number of stomata, plant height and harvest index contributed more to the blast resistance.

b) Biochemical basis

Maheshkumar (2002) working with phytoalex production in plants found four different phytoalexins produced. Of these, Oryzaaxelin was most effective. Blast incidence was positively correlated with grain protein content in all the environments. Cultivars with higher protein were susceptible to blast than those with low protein content. White grain cultivars were in general, have more grain protein content and thus were more susceptible than the brown seeded cultivars, which were normally less in grain protein content (Dinesh kumar *et. al*., 1985). The infection occurred with increase in protein in seed, but decreased in starch and ash. In all the cultivars, a glucocidase activity was higher and glucose content lower in the diseased portion of the neck ((Pall, 1992). There was a strong association between the seed colour with high seed protein, phenol and tannin with blast incidence. Sugar content and peroxidase activity had no influence on the blast occurrence (Ravikumar *et al*., 1991)

Somappa (1999) reported that certain biochemical contents in blast resistant variety GPU-28 and susceptible variety K-7 were at variance. The latter has higher protein content. The reducing sugar content was higher in dry seeds and 25 days old seedlings at dough stage. Whereas in GPU.28, the total phenol and tannin contents were higher than in K.7, the susceptible variety. Peroxidase activity, polyphenol oxidase and phenyl alamine ammomiase (PAL) and total phenol content were reduced in the blast infected plants.

The pathogen invades the host through stomatal opening or through direct entry by piercing the epidermal cells. The resistant varieties exhibit higher cytoplasm granulation than the susceptible varieties (Madhukeshwar, 1990, 1997b).

Genetic basis of resistance

Seetharam and Ravikumar (1993) worked out the genetics of blast resistance by adopting line x tester analysis approach. The indication was that there was an additive gene action for finger blast. However, five generation mean analysis revealed non-additive gene action for

finger and neck blast. Further, it was shown that for neck blast, both additive and dominance gene effects were significant with the predominance of dominance gene effects. Among epistatic gene effects additive x additive gene effects were important. All the three types, viz., additive, dominance, additive x additive and dominance x dominance gene effects were found important in respect of finger blast. In the case of GE.447 x GE.156 only additive and additive x additive gene effects were significant. The estimates of narrow sense heritability to neck blast was low and medium for finger blast suggesting additive gene effects were not important for the expression of these characters. Further, Ravikumar and Seethasam (1994) observed moderate to high genetic variability for neck and finger blat in populations. Neck and finger blasts showed high heritability and high genetic advance which indicated the role of additive genes action.

The phenotypic and genotypic coefficient of variation was large for finger blast. Both additive and non-additive gene effects played significant role in the expression of blast disease. High genetic advance manifested by the disease suggested the scope for the improvement of this character with simple selection (Byregowda *et al*., 1997 and 1999a).

Sources of resistance to blast diseases

Blast, indeed, is a severe disease, often causing crop losses up to 50% and above. This signifies the fact that resistance breeding commands top priority. But the important thing is the availability of variation for resistance at the population level.

The first-ever observation on the existence of variation for this disease was by Thomas (1941). Eversince, more exhaustive work has been done by several workers and a comprehensive list has been prepared as in the following statement by Anil Kumar, Mantur and Madukeshwar during 2003:

Sl. No.	Varieties / cultures	Reference
1	IE.120	Ananymous, 1970
2	PR.722	Deshker *et al.*, 1973
3	TAH.91-1,TAH.8	Pall and Nema, 1978
4	APV.27	Rath and Swain, 1978
5	KYO.127	Mochisuki *et al.*, 1978
6	Rampur local	Tamong, 1982
7	TE.882,IE.1941, U.47, U.10, U.45, GE.304, GE.713	Seetharam and Viswanath, 1982
8	IE.203, IE.207, E.215	Singh and Gupta 1983
9	IE Nos: 5, 27, 28, 765, 416, 596, 708	-
10	Nirmal	Gupta and Singh, 1983
11	KM. 31	Gupta and Singh, 1985
12	IE. 1012, HPB.96 – 11, MR.1, MR.2	Viswanath *et al.*, 1987
13	Kakeri	Patnaik *et al.*, 1987
14	Co.12	Sundareshan, 1988
15	P.248, P.277, IE. 882, IE.891, T.249, 410, GE.746	Sharma *et al.*, 1988
16	GE. Nos: 1273, 1276, 1505, 1796	Lucy Channamma, 1987
17	GE Nos: 75, 669,866,1309,1407, 1409	Ravikumar *et al.*, 1992
18	GE. 2362, GE. 232, GE.769	Pall, 1991
19	GE.1170, GE.1309, PR.1158	Somashekar *et al.*, 1992
20	VL.149	Devendra Mohan, 1993
21	GE.5016, GE.6002	Shrehan and Baniya, 1993
22	GE.411, IE.3207	Naik *et al.*, 1993
23	TNAU.551	Ramaswamy, 1995
24	286 accessions in germplasm	Ramkrishna, 1997
25	36 accessions in germplasm	Viswanath *et al.*, 1997
26	GE Nos: 406, 669, 705, 1293, 1309, 1409, 1546, 3510	Gupta and Prasad
27	IE. 2897, 2912, 2885	Fakrudin *et al.*, 2000
28	36 cultures from germplasm	Somappa, 2000
29	AKE, 1033, MR.2	Rajanna *et al.*, 2000
30	GE.2400, 4913, 4914, 4915	Mantur *et al.*, 2001a
31	GPU.28, GPU.45, GPU.48	Mantur *et al.*, 2001b
32	GE.669, 676, 632	Sunil, 2002
33	GE Nos: 250, 261, 263, 320, 338, 344, 352, 416, 357, 371, 383, 396, 398, 400, 406, 409, 416	Shanthakumar, 2002
34	MR.1, GPU.56, GPU.58, VL.321	Ramappa *et al.*, 2002b

Source: Anil Kumar *et al.* (2003), AICSMIP, UAS, Bangalore.

Further, Mantur *et al*., (2002) evaluated 18 lines over the years 1996 to 1999 at UAS, Bangalore and found genotypes IE. 18 and GPU.28 were free from neck balst, while GPU.26, VL.149, VL.253 were free from blast. The neck blast incidence in MR.1 was only 1.33% and in GPU.28 it was 2% as against 30% in PR. 202 during kharif 2000 in Mandya and Mysore districts of Karnataka (Ramappa *et al*., 2002b). Sanath Kumar *et al*., (2002b) studied an early event of infection and found there was a significant reduction in the length of germ tube, appresorial- development, size of the leisions and number of spores per leision in the resistant genotypes compared to susceptible ones. Kishore Shrehan and Bimal Bamia (1993) listed PR.202, GE.5016, GE.6002 and Rillicarbo as resistant in Nepal. Elobu and Adipala (1993) found a variety Ekama to be less susceptible to blast in Uganda. In a study on variability for grain and related traits in 196 germplasm accessions in Malawi, variation in the incidence of finger blast among them was significant (Mnyenyembe and Gupta. 1998).

Seedling and leaf blight

This disease is caused by *Helminthosporium nodulosum*. Subramanian (1971) transferred this genus to *Drechslera* and thus renamed it *Drechslera nodulosa*. It is next to blast in severity on ragi and hence claims importance. It is most widely distributed in almost all the ragi growing parts of the world such as India (Coleman, 1920), Uganda (Sydow, 1927), East Africa (Castellain, 1938), USA and Philippines (Butler, 1918), etc. In India, it is found in most parts of the country (Govidnu, 1982; Mitra, 1931; Thomas, 1940 and Narain *et al.* 1975). Although it was not considered a severe disease, however, in combination with *Fusarium culmorum* and virus, it occurred in a devastating epiphytotic form in South India way back in 1965-66 (Govindu and Shivanandappa, 1967) and caused heavy loss to the crop.

All the parts of the plant are prone to attack, especially at the seedling stage. It is seedborne and thus seedlings are often affected and die before they emerged. Leaf leisions appear in plenty and they are small, oval, brown spots, which gradually elongate parallel to the main axis of the leaf. Whereas the leisions on the leaf sheath appear much larger in size and are dark-brown in colour. They commonly occur at the junction of the leaf blade and leaf sheath. The symptoms on the leaf sheaths, culms and internodes usually appear as large, irregular, dark-brown to nearly black blotches. Under severe infection, the entire node and internode, especially at the basal stem position become involved. In addition, blackening of the collar region in most of the affected plants was observed during epiphytotic form. The entire earhead in the infected plant becomes dry. The grains may not develop fully and thus they become shrivelled, leading ultimately to heavy yield loss.

Shankar and Shetty (1989a) observed the disease symptoms on glumes, palea, lemma and seeds from hard dough stage onwards. However, the concentration of fungal spores was maximum on leaf surface at flowering stage.

Several species of *Helminthosporium* were reported to occur on finger millet. McRae (1932) and Mehta (1934) observed the occurrence of *H. leucostylum*, which was less severe than *H. nodulosum*. There were more species reported such as *H. holmii, H. tetramera* and *H. rostratum* (Singh and Misra, 1978; Vasudeva, 1960, Lele and Dhanraj 1966).

Luttsell (1956) first reported *Cochliobolus kusanoi* as the perfect stage of *H. nodulosum*. After realizing variation in the conidial stage of *C. kusanoi* from that of *H. nodulosum*, he described it as a new species called C. nodulosus (Luttsel, 1957). The causal organism is present both intra and interacellularly in the host tissue in the form of septate light-brown hyphae, which produce conidiophores that emerge through epidermis. The long conidiophores are septate, dark-brown at the base and sub-hayline at the tip and measure 80-250 x 5.7 m thick walled 3-10 septate conidia are borne singly in succession at the tip of the conidiophore. They are obovate to cylindrical, tapering at both ends with a hilum at the base measuring 40-110 x 11-21 m. They germinate by germ tubes from the end cells, either singly or one after another. As many as 11 conidia may be formed on one conidiophore. They are thick walled and light russet-green in colour.

The pathogen produced sexual fruiting bodies in culture, which posses cylindrical beaks, black in colour and spherical in shape. These ascocarps (perithecia) measure 276-414 in diameter, the beaks are 97-262 m in length and 55-83 m in breadth. The asci are short and straight with 1-8 ascospores whose apex is rounded. They measure 120-193 m x 14 -17 m. Asci are embedded in pseudoparaphyses. The

ascospores are spirally coiled within the ascus. They are hyaline, filiform and 11- septate. (Pande and Shukla, 1977).

The pathogen is known to infect *Eleusine indica, Dactyloctecium aegypticum, Setaria indica, Echinochloa frumentaceac, Panicum miliaceum*, pearl millet, sorghum and sugarcane (Mc Rae, 1932, Mitra, 1931, Mitra and Mehta, 1934), wheat, barley and oats (Thomas, 1940).

The temperature range for infection of *H. nodulosum* was between 10^{o}c to 37^{o}C with an optimum at 30^{o}C to 32^{o}C (Mitra and Mehta, 1934). It requires more than 95% RH for good spore germination. More than 80% spores penetrate the host within 4 hours of inoculation and they take 24 hours to express. The spores carried on the seeds remain viable for one year (Narasimhan, 1933). Vidyasekharan (1971) studied the survival of the pathogen in the soil for 18 months. Reddy and Luke (1979) developed technique to maintain virulence of the pathogen by baiting the fungus on ragi culms.

Most of the present day varieties of ragi are relatively less susceptible. Despite this, the damage by the pathogen to the seedlings in the nursery under warm, humid conditions or to the developing seeds in the ear are considerable.

Venkatakrishnaiah (1935) suggested seed dressing with Fermate or Agroson in addition to Cereson. Agroson was found to be more effective (Grewal and Pal, 1965). Capton was found to be the best followed by Erestan and Duter (Hegde and Shivanadappa, 1968). Morestan and rhizome extract of *Canna* plant extracts inhibited the spore germination. (Ahmed and Sullia, 1973). Treatment of seeds with Panoctine plus (Guazatine + imazolil) was not only effective against seed borne *H. nodulosum* and also increased germination (Ranganathiah, 1978).

Jagannathan and Narasimhan (1988) evaluated *in vitro* 66 extracts of plant products and found that a synthetic product from garlic oil or neem oil, neem leaf, parthenium leaf, turmeric rhizome and garlic bulbs was effective in inhibiting spore germination and mycelial growth. Application of Cumin (0.3%), once at flowering and again after 15 days later helped in controlling the disease (Patra, 1996).

Coleman (1920) observed differences among varieties about the level of resistance to seedling blight. According to thim, the varieties with green glumes were more susceptible than those with purple glumes. Govidndu *et al*. (1970) evaluated 806 varieties from India, Africa and USA under field conditions and found as many as 139 lines were resistant. The least incidence was found with two progenies, 7-74-2-1 and 5-25-3-1 by Sanne Gowda and Viswanath (1986). Six germplasm lines; GE Nos. 130, 250, 404, 510, 676 and 1423 were found resistant. Somasekahar *et al*. (1988) screened 25 genotypes at Bangalore and found that TNAU.332, PR. 202 and GE.130 showed partial resistance. Govindu and Keshavamurthy (1976) listed varieties, which have combined multiple resistace to blast, foot rot and leaf height.

Foot Rot

Foot rot on ragi was first reported in India by Coleman (1920) and from Sri Lanka by Park in 1930. In India, it is present in Andhrapradesh, Tamil Nadu, Karnataka and Odisha (Mc Rae, 1928) Small (1925) reported from Uganda. Although, it was prevalent on all the varieties, it was of little economic importance (Elobu and Adipala, 1993). Loss of crop on account of foot rot in Rampur, Nepal was said to be around 50%.

The disease is caused by *Selerotium rolfsii* in imperfect stage and in Basidial stage, it is called *Pellicularia rolfsii.*

The basal portion of the plant initially appears watersoaked due to infection by the pathogen. Later, this portion turns brown and then becomes dark-brown and the affected portion of the stem shrinks. White cottony mycelial growth occur profusely in this area. Roundish small white velvety grain like structures appear in the fungal matrix. These grow, attain the size of mustard seeds and turn brown. They are the Selerotial bodies. Mean while, the leaves lose their luster, drop and dry, ultimately leading to the death of the plant.

Sandy loam soils favoured the disease incidence and the pathogen survived better at low moisture levels (Sujatha, 1991). The disease incidence is more during warm and dry months. Under Bangalore condition, the disease incidence was more in February- April months (Viswanath and Channamma, 1987). Further, Selerotium – nematode complex was also reported (Govindu and Swamy, 1966). Maintanance of good drainage helped check the disease impact.

The fungicide PCNB reduced the severity upto 65%. Quintozene was also found to be good to control the disease (Govindu *et al*., 1966). Channamma *et al.* found Duter, a tin compound and Vitovax were more effective and better than Brassicol in controlling the disease.

To identify the source of resistance to *S. rolfsii* and nematode disease complex, Govindu and Swamy (1977) screened 884 lines from the germplasm and found 322 accessions were resistant, 239 intermediate and 323 susceptible. Sannegowda and Pandurangegowda (1984) found many of the varieties like Indaf.3, Indaf.78 and Indaf.9 were less prone to disease. Out of 21 accessions tried over three years, Jain *et al*. (1994) found PPR. 1735 to have stable resistance. Batra and Tamong (1983) reported Rampur local from Nepal was highly resistant.

Smut Disease

Smut disease is caused by *Melanopsichium eleusinis*. It occurs at random in the earhead. Diseased grains are transformed into galls or bullete bodies, which are six to seven times more than the normal size of the grain. The affected grains are single, and some times appear in groups in the form of patches of varying sizes. The other type of symptom was that the inflorescence remained extremely reduced in size containing only shrivelled grains. There was complete absence of development of spike or spikelets including glumes, which were replaced by greenish, globose to elongated sac-like structures filled with sooty telio spores (Vijayaraghavan and Patil Kulkarni, 1922).

Another type of symptom was that the sori were found to occur around the stalk of the main rachis of the inflorescence in the form of galls, scattered or colesced with each other containing mass of teliospores and, sometimes, there were abundance of small and elongated sac-like small sori resembling phyllody instead of developing into normal grains. Colour of the fully developed sori were brown or chocolate brown and on the white-grained varieties, the matured sori were dull-white or bluff coloured.

The disease was first observed in erstwhile Mysore State in India (Coleman, 1920). In Maharashtra, it occurred around that time at Malkapur near Kolhapur in erstwhile Bombay State. It was also reported from Tanzania. Sydow (1929) described this disease in *Eleusine indica* from Nankang, China as a new species.

The pathogen was first named as *Ustilago eleusinis* by Kulakurni. But later, it was transferred to the genus *Melamospsichium* and then renamd it as *M. eleusinis*. The spores are globose. The epispore is distinctly pitted with a rough surface.

Infection was air-brone and floral infection occurred when sporidial suspension was found over the earhead at the time of emergence of the head. It was also reported that infection occurs when the soil was inoculated with teliospores at the time of the plants nearing heading stage. The disease was also reproduced when the teliospore suspension was inoculated into young inflorescence yet in sheath.

Spore germination was low, erratic and irregular, maximum germination occurred with in 24 hours of incubation of freshly collected spores (Ganapathi, 1971). The optimum temperature for spore germination was 25^{o}C. There were two types of germination:

a) Mycellial type: Germination first started as a small hyaline, straight or sent tubes and gradullay elongated into a slender hypha.

b) *In sporidial type*, Germination starts with the appearance of a small hyaline germtube, which gradually elongated and became promycellium. Two transeverse septa were formed dividing the promycellia into 3 to 4 cells. Promycellia gave rise to lateral sporidia

or short branches near the septa. The sporidia were ovate or cylindrical rarely spindle shaped. Uninucleate and thin walled.

Vijayaraghaven and Kulkarni (1977) suspected the presence of physiological specialization of the fungus; but no proof was produced.

Teliospores were studied by Khanna and Payak (1971) through electron microscopy. This revealed that the surface was densely echinulate and showed some type of outgrowths. The large sized conical projections were sharply pointed. In addition, numerous small outgrowths called 'spinulae' or 'papillae' were also present.

As for control methods, it was felt that since the conidia of the pathogen were air-borne and infection being restricted to a few flowers, chemical control method was non-viable. Yet Hiremath *et al*. (1985) evaluated *invitro* a few fungicides and found Bavistin was highly effective. However, least infection was noticed when Difolatan was sprayed at panicle initiation stage followed by a Mancozeb spray at flowering stage.

Since this disease is not that distructive as blast, and also ragi being low value crop, resistant breeding is a desirable option. Sannegowda and Viswanath (1986) screened 139 lines during kharif and summer during 1985-86. The maximum incidence of the disease in kharif was 20.38% and the same was 46.16% in summer. However, 4 entries were found to have stable resistance during both the seasons. Further, a set of 79 accessions were screened during 1990-91 under the AICSMIP at Bangalore and found that the disease incidence in general was 80% in certain accessions. Despite that, a few genotypes such as GE. Nos. 2700, 3858, 3061, 3075, 3093, 3542 and 4146 were found resistant.

Mantur *et al*. (1996) screened 94 genotypes over two seasons at Bangalore and found that the genotypes sprayed with sporidial suspension from 10 days old cultures at flowering, the incidence of the disease ranged from 0 to 62.4%. Yet accessions like GE. Nos. 1309, 2856, 4454 and GPU.25 and GPU.26 were free from smut infection.

Apparently, there are some good sources of resistance in the population and if they are properly dovetailed into breeding strategies, a good number of resistant varieties combined with desirable agronomic features could be evolved.

Downy Mildew Disease

Downy Mildew disease is relatively a severe one on ragi. But its occurrence is sporadic (Anilkumar *et al*., 2003). This disease was first reported by Venkatarayan (1946) in erstwhile Mysore state in India. Ananthanarayana (1963) mentioned its presence in Pune in Maharashtra. Some confusions existed about its nomenclature and it was finally cleared by Thirumalachar and Narasimhan (1949) who identified the pathogen as *Sclerospora macrospora*, a name originally proposed by Saccardo (1890).

The pathogen has been reported from USA, Japan, Italy, Australia, France, Canada, Peru, erstwhile USSR, China, Germany, South Africa, Maritius, Bulgaria, Mexico, Pakisthan and erstwhile Yugoslovia on various hosts. Safeeulla (1970a) made a detailed study of downy mildew on sorghum, pearl millet and ragi. Govindu *et al.* (1970) gave a report on the then status of downy mildew disease on ragi in Karnataka, India.

Sclerospora macraspora has wide range of hosts in the family Gramineae amounting to as many as 141 hosts. Detailed review of the genus Scleropspora was made by Safeeulla and Shaw (1962), Payak *et al*. (1970) and Raghavendra (1974) on various aspects of downy mildew.

Symptoms of the disease are that the infected plants are generally stunted in growth with shortened internodes, crowded leaves giving a bushy appearance and are often pale-yellow and transluscent spots are seen on leaves. The most striking feature of the disease is either completely or partially, proliferated spikelets into leafy structures (Safeeulla, 1976). Mycelium is seen in the embryo and endosperm in the infected seeds. On germination, mycelium spreads to meristamatic

tissues. Leaves, roots, spikes, and seeds are found to have significantly higher amount of total nitrogen than their healthy counterparts. Diseased plant tissues contain Cystin and Tryptophan, which are totally absent in the healthy tissues. Further, aspargin, glutamic acid, fructose, glucose and sucrose contents are also more. However, the Indole Acetic Acid content in mildew spikes is less than in healthy spikes. Chlorophyll contents a, b and total chlorophyll is significantly less in the affected leaves (Safeeulla, 1976).

The life cycle of the pathogen was described by Safeeulla (1955). The white colony growth is generally not seen in the diseased plants. The first sporangium is formed at the apex, which is followed by the development of sporangia in lateral positions. These are lemon shaped with a prominent apical papilla and pedicel. They germinate and liberate many unequally, biflagellate zoospores. The optimum temperatue for germination is 22^{o}C to 25^{o}C (Safeeulla, 1976). Maximum germination occurs at pH 6.5, which is also the same for zoospore germination. Sporangia germinate with in 3 hours. Light seems to have very little effect on sporangial germination (Raghavendra and Safeeulla, 1971).

Mycelium is multinucleate and upto 48 nuclei have been observed in the sporangia. Each treatment in the zoospore contains a nucleus. The zoospores are pyriform, spherical or irregular. They germinate by germ line with the formation of appresorium. Eight chromosomes are recorded in each zoospore (Safeeulla, 1976).

Oogonia develop as swellings of the mycelium both in the apical and intercalary positions and contain a number of nuclei. One of the lateral branches from the mycelium develops into an antheridium in the vicinity of oogonium. Mostly one or two antheridia are associated with each oogonium. The nuclei in the antheridia and oogonia divide simultaneously. About 40-100 nuclei are seen in each oogonium. In the mature antheridium 16-24 nuclei are observed. At a later stage, nuclei migrate to the peripheral region and a dense protoplasm mass is commonly seen in the ooplasm with a single nucleus. The nuclei of the periplasm degenerate and helps develop oospore wall. The receptive papilla enters the antheridium before the antheridial tube penetrates oogonium and discharges its content in to the ooplasm.

Eight to 9 nuclei have been observed in the fertilization tube and the remaining antheridial nuclei degenerate. The zygote divides repeatedly and give rise to 30 to 35 nuclei. The oospore develops a thickwall and the matured oospore has three wall layers. The outer most has multinucleate sporangium, which liberates several zoospores (Safeeulla, 1970b).

Zoospores are released at 26-30°C and they infect young ragi seedlings. The pathogen is internally seed-borne (Safeeulla and Raghavendra, 1971, 1978). It has a wide host range and thus disease development becomes easy. The infected grass hosts survive much longer than usual period thus aiding perpetuation and dispersal of the pathogen.

Venkataraman (1956) observed green ear disease to be more severe in transplanted ragi. Similar observations were also made by Govindu *et al.* (1970). While it has a wide range of hosts, the most important economic plants known to get affected by the downy mildew disease are oats (Noble, 1934), barley (Whitehead, 1955), rice (Yamada, 1911), pearl millet (Safeeulla, 1976), sugarcane (Staindal and Smith, 1952), sorghum (Whitehead, 1958), wheat (Severini, 1913), Corn (Cugini and Traverso, 1902) and so on.

Systematic infection occurs at seedling stage. Seed treatment with chemicals, Apron and Ridomil MZ would check infection (Anilkumar *et al*., 2003). However, alternative method to control the disease is by breeding resistant varieties. At the university of Mysore (Karnataka) Safeeulla (1976) tested 360 varieties of ragi and found as many as j175 varieties did not get infection, while the rest in the test plot had infection ranging from 58 to 100% (Safeeulla, 1976).

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HARVEST AND POST-HARVESTING TECHNOLOGY

Advent of modern agriculture has brought in its wake many problems to small and marginal farmers. The case in point is ragi / finger millet (*Eleusine coracana*) cultivation, which is practically a dry land crop in arid and semi-arid tropics of Asia and Africa. It is grown as a pure crop and sometimes inter-cropped with some legumes such as field been *(Lab-lab purpurius)* Pigeonpea (*Cajanus* cajan), fodder crops like sorghum, oil seeds like niger, castor bean and so on. Though it is grown as an irrigated crop, its proportion is rather marginal.

Harvest and post-harvest operations, unlike in most of the dryland grain crops, involve multiple operations: harvesting, threshing, winnowing to separate the grain from chaff, pearling, storing and so on. All these operations are being presently done through traditional methods involving mannual labour. So much so, these operations are labour and cost-intensive besides being time-consuming and drudgerous. Consequently it is losing out to other crops inspite of the fact that its grain is rich in food and nutritional properties and animal feed values of the crop residues.

Harvesting

When the crop is mature, harvesting is being done by a traditional method with sickles, Either the whole plant is cut at the base together with the earhead or sometimes only earheads are harvested first and then stalk is cut. However, the whole stalk harvesting including earheads has been a common practice from times immemorial in India and is still being followed to a large extent. Earhead turning deep-brown in colour with approximately 22 to 27% moisture content of the grain is the sign of maturity (Krishnamurthy *et al*. (1986) and the right stage for harvesting.

When the total crop is harvested, it is bundled and stacked in the field and later transported to threshing yards specially made for the purpose. In recent years some improvements have been made in the indigenous sickle by introducing carbon steel, which precludes frequent sharpening of the serrations on the cutting edge. Its advantage in other aspects of harvesting is rather marginal. In the other method, only earheads are cut first and then the stalk. The stalk is bundled, dried in the field itself and transported later and stored in stacks and fed to the animals as and when needed all through the year.

Many attempts have been made to innovate and fabricate a mechanical harvester exclusively for ragi. Murthy and Gowda (2005) modified the existing rice and wheat harvester, which contained self-propelled reapers. Here the belt power transmission was by a system with a combination of universal joints and incorporated stronger pressure by hitching to a 15 hp power tiller. Its performance was evaluated with a recently released high yielding variety GPU.28 at Bangalore. It was found that its overall efficiency, as measured by the height of the stubbles left behind, speed of operation, man and mechanical hours required, fuel consumption and wheel slippage was good at 96% field efficiency. Further advantages were 50% of saving of operational time and 60% of costs as compared to traditional operations with sickle.

Threshing

Threshing is generally done by beating the well-dried sheaves spread evenly in the threshing yard and beating with sticks or passing of bullock or tractor – drawn granite stone roller repeatedly over the sheaves in the threshing flour. Then the straw and the grains with husk are separated and then grains are separated from the chaff by winnowing. This is a time-testing and boring operation since it has to be done only when there is a blowing wind current, which is often indefinite and one has to wait for days together to complete the operation.

Though stone roller threshing has been practiced traditionally from ancient times, no one seems to notice the damage it has done to the

grains by way of breakage. It did not seem to be significant because the threshing is done when the grains are well dried and become hardy. However, Kamar and Batagurki (2001) considered the level of moisture content in the grain as crucial to prevent the grains from breaking. Thus the moisture levels were maintained at 18-19, 13-15 and 10% (wet basis) and threshing was done through mannual beating with sticks or passing a bullock or tractor – drawn stone roller or employing a rasp bar type mechanical thresher. Post-operative features like output, threshing efficiency, mechanical damage, cost-effectiveness between different methods of threshing were evaluated. It was found that rasp bar type multicrop thresher was the best. It has an output of 138.46 kg/h of grain, threshing efficiency of 79.6%, mechanical damage of 2.95% and the operational costs, on the basis of 2001 prices, were Rs. 18.43/q.

The mechanical device used here consisted of a combination of 4 mm conclave clearance, 1200 m/minute (1000 rpm) thresher drum speed at grain moisture content of 10% (wet basis). It revealed that grains threshed at lower seed moisture content recorded the higher percentage of mechanical damage. However, there was no difference between the two varieties (MR-1 and HR – 911) tested in terms of mechanical damage. The rasp bar type mechanical thresher worked very well if it was used only for threshing earheads. If it was with both earheads and sheaves together, threshing efficiency went down by 50%. Further, straw quality of the sheaves also suffered. In ragi, the farmers would not prefer to risk the straw quality (Krishnamurthy *et al*. (1986). One other advantage with the mechanical threshers was that there was no need to do winnowing separately.

Pearling or degluming

Modern ragi varieties have longer glumes, often up to covering of the whole grain, and are ordinarily difficult to remove them during threshing. Freeing the grains from glumes is important as they affect the marketability of grains on the one hand and quality of the grain on the other. The removal of glumes is called pearling or degluming.

In recent years, many pearlers have been developed of which the one done at Tamil Nadu Agricultural University, Coimbatore was said to be fairly good.

It was originally developed for sorghum. It consisted of a series of Carborundum cylindrical wheels, which were mounted on a horizontal shaft without any clearance between the wheels. The rotor was mounted in a metal case with a clearance of 1.5 – 3.0 cm at the sides and at the bottom of the rollers. A screw of 2 pitches and a pitch length of 1.5 cm were provided at the inlet of the shaft. An aspirator at the outlet removed the fine particles produced during abrasion. The unit was of low capacity and powered by a one hp motor. Operational efficiency was maximum when moisture content of the grain ranged between 10-12% (Ramkumar *et al*., 1988 and Krishnamurthy *et al*., 1988).

Storage

Grains are smaller and roundish with thick outer coat and fairly well insulated against the storage pests and diseases. For indoor storage in small quantities, coal tar drums, metal bins or conical mud vats are generally used. For temporary storing, gunny or polythene bags are used. For bulk storing, under-ground outdoor pits dug upto one meter and a half or 2 meters at an elevated ground (lest the moisture would seep in and damage the grains) are considered safer for longer storing. They are in local parlance called “Hagaves”. It is remarkable that grains are preserved (stored) in an excellent condition even after storing for few years in these hagaves. But only prerequisite is that the grains should not come in contact with moisture. The grains are also safer from infestation by store pests.

Milling

Ragi products are prepared and consumed when they are milled into flour. There are many flour mills operating everywhere. But before milling, the grains should be cleaned of residuary glumes, stones, dust and other extraneous material. Some mechanical devices for removing stones and dust have become available as an adjunct to flour mills in recent years. They do not need any independent power source as they are attached to existing flour mills. The advantage is that it economizes time and costs involved in manual operations.

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FOOD AND NUTRITION

A large proportion of people in Africa and India, whose staple food is ragi-based, generally lives on subsistence economy. Malnutrition and under–nourishment is a most debilitating scourge among those people due to dietary deficiency of low calory food containing less protein and other nutritional elements. This has drastically impacted the growth and development of the working group of people and the children mostly in the age group of 6-10 years. The diminished energy quotient has seriously hampered the work output which directly affected the economy of the people and quality of life. Ragi diet, even with a minimum of other accompaniments, is believed to ameliorate highly abhorred problem of hunger and malnutrition (Devos, 2005), because ragi grain is naturally rich in nutraceuticals essential for quenching the problem of vulnerable people.

Chemical composition of ragi grain

Most of the three fourths of the ragi grain by weight (75%) is composed of carbohydrates. Fats and lipids though less in proportion are of high quality due to the presence of more free fatty acids and the lipid profile is free from cholesterol. Crude fiber content is around 3.6%, which is higher than in rice and thus good for the people suffering from digestive disorders.

Protein content

Protein content of the present day varieties ranges between 8-11%. However, a white-grained variety *Majjige* and its hybrid derivative *Hamsa* are reported to have 14% of protein. These varieties are currently not very much preferred either by the farmers or by the consumers because of low yield profiles of the varieties and peach coloured grains, respectively.

It is not the quantity of protein alone that matters in nutritional terms in as much as that of its amino acid composition and its balance,

digestion and absorption. Lysene is the chief ingredient of the amino acid composition. Lysine value is higher in hybrid varieties. But there is a negative correlation between protein and lysine contents. PER (Protein Efficiency Rago), value, which implies the amount of gain in weight obtained from the given unit of protein, is another important parameter that determines the quality of protein and through which the grain as a whole. PER value is only 1.2, against 1.8 scored by other millets since the digestibility of whole grain of ragi is less than 87%. But when protein of ragi absorbed by the body as nitrogen and retained are considered, the latter's biological value is 89.9% compared to 80-84% of rice and other millets (Vaidehi, 1986).

Protein content in ragi is not stable. It could be increased by increasing the prolyamine storage protein over other protein fractions (Virupaksha, 1986). Further, Marimuthu and Rajagopalan (1995) tested by growing the crop under variable levels of nitrogenous fertilizers and found that it was not constant and /or consistent at all the levels of nitrogen input. Varietal variation was also reported by Barbeaw and Hilu (1993) that protein composition in wild progenitor of finger millet (*Eleusine corocaa* ssp. *africana*) was significantly higher in 4 out of 6 domesticated accessions. Marimuthu and Rajagopalan (1995) observed in the field experiment that protein content was highly sensitive to environment and that, therefore, would not serve as a selection criterion in breeding processes.

Total minerals

It is rich in total minerals. Samanthray *et al*. (1988) analyzed varieties and recorded that there was 5.4 -6.2% calcium, 4.8-6.0% potassium, 0.09-0.014% sodium, 0.9-1.0% copper, 1.9-2.9% magnesium, 0.2-2.0% iron, 23-50% zinc, sulphur 1.6-1.9% and phosphorus 0.150-0.406 mug/g. Calcium content was higher in malt than in seeds and seedlings. White ragi varieties have more iron (Fe), Zn, P, Ca, Cu and Mg than the brown and black seeded varieties.

The wild progenitors of cultivated varieties have significantly more Ca and Fe than their cultivated counterparts (Barbeaw and Hilu, 1993).

Varietal variation was also observed by Shashi *et al*. (2007) in respect of total minerals as compared with the varieties GPU.28 and Indaf.5, which were used as checks. It was found that the composition of calcium was in the range of 264-365 mg/ 100g, Magnesium: 66- 130 mg / 100g, iron: 3.60 – 7.31 mg/ 100g, sodium: 0.60 – 0.85 mg / 100g and potassium: 294 -1160 mg/100g. In respect of bio-accessibility of iron was more in the varieties ML.426 and ML.322 (12.01 and 12.06, respectively.). The bio-accessibility of iron seemed to be associated with high composition of anti-nutritional elements.

Majumdar *et al*. (2006) observed differences between the hill and base –grown varieties in terms of Ca and Fe. Hilly varieties (550 ft msl.) have slightly lower Ca content, but they had higher Fe content. Puffing of grains reduced Ca and Fe contents to 1.3 and 2.03, respectively.

Vaidehi (1986) observed that no other millet or cereal grain was as rich as ragi in respect of total minerals in general and calcium and iron contents in particular. Iron deficiency causes aneamia, which is rampant in India and other developing countries. So diversified ragi food products seemed to have improved the situation.

The other essential nutritional elements are Thiomine and Carotine. Thiamine at 0.42 / 100 is equivalent to that in maize. However, carotene is higher than in rice. And so are magnesium and copper, which are adjunct to utilization of other nutrients in the body.

Anti-nutritional elements

High protein content does not necessarily mean high nutritional superiority of the grain unless it is properly digested and obsorbed. However, it is interfered with by the presence of proteinase inhibitors, lectins and polyphenols amongst which tannin fractions are most anti-nutritional. And they are present at higher levels in the finger millet grain. But their adverse interference with digestibility and absorption could be minimized, if not totally climinated by the processes of dehulling, parching or roasting, besides significantly improving the

biological value of protein. Trypsin, which is another anti-nutritional element, could be eliminated by cooking various products before consumption. Shobana *et al*. (2007) reported the other nutritional elements like alpha glycosidase and pancreatic amylase play vital role in the clinical management of post-prandial hyper glycemia.

Varietal variation was observed in respect of anti-nutritional factors by Shashi *et al*. (2007). Phytate content was more in the variety ML.197 (320 mg/g) and the least in the variety ML.365 (246 mg/g). Similarly the highest tannin content with 0.54% was found with the variety ML.197, but it was the least at 0.2% with the variety ML.365. Bio-access-ability of iron (Fe) was reported to be associated with high composition of anti-nutrients like phytates and tannins, but it was less in the variety ML.197 due to the presence of more tannins and phytates.

Anti-oxidant activity

Anti-oxidant activity is determined by the P-carotineen-linoleic acid assay which indicated that anti-acid activity was the highest in seed coat extract at 86%. But it was only 27% in the whole flour extract. The seed coat extract showed higher anti-microbial activity against *Bacillus cereus* and *Aspergillus flavus* compared to that in whole seed extract. This indicated that seed coat of finger millet could be an alternative natural anti-oxidant and food preservative (Viswanath *et al*., 2009).

Malting of ragi grains and weaning foods

Malted grains are used for making infant foods in India. Low cost balanced foods based on blends of malted ragi flour, groundnut flour or soyflour, chickpeaflour, fortified with lysinc and methionine improve the nutritive quality of blended foods. They are very good source of essential nutrients that would meet the protein-calory requirements of weaned infants and pre-school children and other vulnerable class of people.

Malting of five finger millet varieties resulted in the significant changes in nutritional composition, neutral detergent fibre, crude fat and ascorbic acid contents. Sensory evaluation of 'burfi' prepared from malted flour showed that overall acceptability scores of all the genotypes ranged from good to fair when rated by the panelists (Sangeethakumari and Sarita Shrivastava, 2000).

Mallesh and Klospfenstein (1998) observed that the yield and composition of malting fractions of sorghum, pearl millet and finger millet malts were 86, 85 and 78%, respectively, and their protein and crude fibre contents were 10.4, 15.5 and 4.5% and 1.2, 1.0 and 1.8% respectively. The lysine content of finger millet malt flour protein of 3.4% was higher than 2.16% of malt of pearl millet and 1.45% of sorghum malt flour protein. The bran fraction of pearl millet was a rich source of protein (23.1%) and fat (9.3%)

Malleshi *et al*. (1996) observed that physical and nutritional qualities of extruded weaning foods containing sorghum, pearl millet or finger millet flours differed between themselves. Sixty percent of each of them were blended with toasted mungbean (*Vigna radiata*) (30%) and dried skimmed milk (10%) and extruded to make pre-cooked, ready-to-eat weaning foods. Total dietary fibre content of the foods ranged from 7.6 to 10.1% with soluble dietary fibre content of foods being about 10% higher than that of corresponding blends. Extrusion enhanced the *in vitro* protein digestibility of food and no marked difference occurred with *in vitro* carbohydrate digestibility among the unprocessed blends and extruded foods. Net protein ratio, protein efficiency ratio and biological values were higher for the finger millet food than for pearl millet food. It cold perhaps be due to higher lysine content of finger millet protein.

Ragi-based products of local interest were formulated by utilizing whey protein concentrate (WPC) so as to enhance their nutritional profile. Sprayed WPC having 40% protein was used at 10-40% to replace ragi flour and the products such as ragi malt and ragi *dosa* were prepared by following the regular recipies and subjected for

sensory evaluation and bioassay studies. The results revealed that malt and ragi *dosa* were best accepted at 30% level of WPC supplement and the products had protein content of 14.8% and 14.2% of ragi malt and ragi *dosa*, respectively, as compared to that of control with 11.4 and 11.9%, respectively, (Tripathy *et al*., 2003). Animal feeding trials on albino rats revealed that the samples with WPE had PER value at 2.2 and 1.6%, respectively, as against 2.6 with controls. Experimental samples also showed satisfactory feed efficiency ratio and apparent digestibility as compared with control diet. This showed that WPC could be conveniently used in the formulation of ragi-based products to enhance thir nutritional profile.

Digestibility indices (DI) of ragi-based preparations like dumplings *(mudde*). *roti, puttu* and *dosa* without accompaniments like sauce (chutney) or *sambar* were determined by measuring the rate of starch hydrolysis *in vitro*. Digestibility was then compared by replacing ragi with other cereals such as rice, wheat or sorghum in similar preparations. Percentage starch digestibility *in vitro* and digestibility index ranged from 17-27% and 66 – 94%, respectively. The proximate composition rate of starch hydrolysis and glucose release were affected by the degree of gelatinization, ingredient and accompaniment rather than cereal base. Scanning electron microscopy revealed a complete disintegration of starch in dumpling (Roopa *et al*., 1998).

Tannins reduced the digestibility and absorption. This could have been set right through proper cooking processes. Magnesium content was very high compared with milled rice and/or par-boiled rice. Copper also high. Lysine value is higher with hybrid varieties. Malted ragi had good aroma and had acceptable sweetness (Vaidehi 1986).

Vanashree *et al*. (2008) studied the quality characteristics of ragi-based *idlis* (breakfast food in India). The major ingredients included ragi flour (RF), parboiled rice (PR), black gram (*Phaseolus* mungo) (B), black gram dhal flour (BF) and ragi (R) processed differently and used at different ratios to prepare 4 variations of *idlis*. RPRB. 1.5: 1:1, RP. 3:1 RFB. 3:1 and RFBF. 3:1. Physical and functional characteristics and acceptability were evaluated. The degree of gelatinization was higher in *idlis* prepared with whole ragi and black gram dhal. The bulk density of ragi flour was higher than that from rice and black gram dhal and the product was softer, easily digestible and absorbable. But the colour of the product was darker, yet acceptable. This indicated that whole ragi could replace rice in the preparation of *idlis* of quality without affecting the sensory qualities of the product.

A popular wafer-like *papad* was prepared by substituting 50% mixture of black gram dhal flour and sago flour with finger millet flour and compared with *papad* made of black gram dhal for sensory attributes, dough characteristics, rolling properties and nutritional quality. Finger millet flour had higher sensory score of 4.7 on a five point Hedonic scale. *Papad* made from ragi flour was rich in Ca (102 mg%) in roasted and it was 109 mg% in fried *papad* relative to that made of black gram dhal, which had 82 mg% in roasted and 99.6 mg% in fried. Substitution of ragi flour did not affect the quality characteristics of *papad* (Vidyavathi *et al*., 2004)

Evaluation of nutritional characteristics of finger millet-based complementary foods

Evaluation of complimentary foods was done by Mbithi-Mwickya *et al*. (2002) at Ghen University, Belgium, Finger millet, Kidney beans (*Phaseolus vulgaris*), peanuts (*Arachis hypogea)* and mango (*Mangifera indica*) were processed separately and then combined. On the basis of their amino acid scores and energy content, complementary food was formulated for children of weaning age. The finger millet and kidney beans were processed after germination, autoclaving and lactic acid fermentation. The mixture containing, on dry matter basis, 65.2, 19.1, 8.0 and 7.7% of the processed finger millet, kidney beans, peanuts and mango, respectively, gave a composite protein with an *in vitro* protein digestibility of 90.2% and an amino acid chemical score of 0.84. This mixture had an energy density of 16.3 kg/g of dry matter and a decreased anti-nutritional

content and showed a measurable improvement in the *in vitro* extractability for calcium, iron and zinc. A 33% (W/V) papa made from a mix of the processed ingredients had an energy density requirement of well-nourished children of 4-6 months of age of three servings a day and at the FAO average breast-feeding frequency.

Ragi-based convenience mixes

Ragi-based convenience mixes (sweet and spiced) were formulated and their storage stability was studied by Premavathi *et al*. (2003) at Deference Food Research Laboratory, Mysore, Karnataka. Three combinations of each mix were prepared, packed in polypropylene pouches, stored at room temperature and at 37^{o}C and then evaluated for chemical and sensory qualities. In the sweetened mix, the addition of beaten rice improved the colour, but increased the rate of liquid oxidation. Whereas incorporation of coconut powder lowered the lipid digestion. In the spiced mix, addition of groundnut increased the rate of oxidation. The hydrolytic changes in terms of free fatty acids increased with the temperature and the period of storage. The sweetened and spiced mixes had a shelf-life of 6 and 4 months, respectively, with acceptability score of 7.7 and 6.0. Statistical analysis of the sensory data revealed that in sweetened mix variation in taste was more associated with overall acceptability, while in spiced mix, taste and aroma were both associated with overall acceptability. The variation between the sensory parameters and taste panel was significant at 1% level.

Popping quality of finger millet

Finger millet genotypes PRM.9802, PRM.1, PRM.701, VL.146, VL.135 and PES.400 were evaluated for physical properties, popping quality, sensory quality and nutritive value of the popped grains (Chaturvedi *et al*., 2008). Varietal variation was significant for popping characteristics. Amber coloured genotypes PRM.701 has higher values for 100 kernels weight as well as crude protein, Ca, Fe and *in vitro* protein digestibility. Prolamine was the major protein fraction and was maximum in amber colour genotypes. Positive correlation was observed between flake size and globulin content of the grain. Popped grains of all the varieties were sensorily acceptable.

Sensory rating of snack items

Ragi was incorporated at different levels to a deep-fried small items like *chekkuli* to study its effect on fat absorption, sensory and storage parameters (Sebastion *et al*., 2005). Three lots of products were prepared incorporating untreated, dry heat treated and gelatinized ragi flour. The control products were without ragi flour. Results indicated that the fat absorbed by the control was 19%. Five percent ragi flour incorporation increased fat content to 24%, but a further increase of ragi flour to 15 to 25% decreased the fat absorption to 19.7 and 18.0%, respectively. Incorporation of untreated and dry heat treated ragi flour resulted in a single decline in the sensory rating of products. But the effects were more adverse with higher levels of ragi flour incorporation. Higher ratings were obtained when 5% of gelatinized ragi flour was incorporated for texture, flavor and overall quality of products in comparison with control. The free fatty acid content of products was very low on zero day and increased during 4 weeks long storage. This showed that incorporation of higher amounts of ragi flour resulted in lower fat uptake, but compromised the sensory quality of the product. However, incorporation, gelatinization as a pre-treatment was found to improve the quality of the product.

Glycemic response to finger millet (Ragi) diet

Glycemic response of rice, wheat and finger millet based diabetic food formulations in normo–glycemic subjects was evaluated by Shobana *et al*. (2007). The dietary products were based on wheat, decorticated finger millet, popped (*aralu*) and expanded (*puri*) rice and each blended separately with legumes, non-fat dry milk, vegetable oils, spices and a few hypoglycemic ingredients were formulated. They contained 17.0 – 18.3% protein, 11.3 to 11.8% fat, 59.9 – 67.5% starch and 13.2 – 18.0% dietary fibre. A 50 gm equivalent carbohydrate fraction of the foods in the form of thick porridge was produced to 8 healthy adults and post-pandial blood glucose was determined. The glycemic index values were 55.4 ± 9, 93.4 ± 7, 105 ± 6 and 109 ± 8 for wheat-based, finger millet-based, *aralu*-based and *puri*-based formulations. The apparent variations in the glycemic index could be attributed to the nature of available as well as non-available (non-starchy poly-saccharides), carbohydrates in the food besides the processing undergone by the cereal ingredients. The higher glycemic index of rice formulations could be due to the easily digestible nature of starches and also their lower dietary fiber contents.

Kumar and Sumathi (2002) studied the effect of consumption of ragi millet on hyper-glycemia in 6 non-insulin dependent diabetes mellitus subjects. All the experimental diets were isocaloric and also contain 75g equivalent of carbohydrates load so that glycemic response could be compared to that of glucose determined by comparing the areas under 2 hr glucose response curve. Consumption of finger millet-based diets resulted in significantly lower plasma glucose levels, mean peak rise and area under curve, which might have been due to the higher fibre content of finger millet compared to rice and wheat. Lower glycemic response of whole finger millet- based diet might have also been due to the presence of anti-nutritional factors in whole finger millet flour, which are known to reduce starch digestibility and absorption. Gum accasia-enriched rice and finger millet-based preparations were studied for glycemic response by Thakkar and Kapoor (2007). The products like *roti, upma* and *idli* were fed as 50 gm carbohydrate portion after an overnight fast to non-insulin dependent subjects and found rise in blood glucose level 24 hours after administration. The gum incorporated products showed very low glycemic index values of 41-48% for finger millet-based preparations. Further, *roti* produced greater glucose lowering effect than *upma* and *idli*. Though gumaccacia enriched rice products also lowered the glycemic index, it was not to the extent of it in the ragi–based foods or breakfast food products.

Beverages

A traditional non-alcoholic beverage *Togwa* is prepared in East Africa from maize flour and germinated finger millet. Maize flour slurry was heated and once stirring upto ~ 80°C and cooled to ~ 50°C and then finger millet malt flour was added to the warm porridge paste and kept at ~ 50°C for 20 minutes. The consistency of the paste was suddenly reduced by addition of finger millet flour and the resultant gel paste changed to viscous liquid, which was kept in a container and incubated at an ambient temperature for 15 hours. After incubation, it becomes sweet and ready to drink without removing any insoluble materials. Changes in the concentration of glucose and lactic acid of *Togwa* during its maturation period was measured using portable, devices until 70 hours of incubation in rural villages of Tanzania in a dry season. Glucose level increased with incubation and reached the threshold value of sweetness. After 24 hours of incubation, the lactose level increased and pH decreased (Kitabatake *et al*., 2003).

Thapa and Tamang (2004) studied a traditional mild alcohol *Kodo Ko Jaanr* (traditional beverage) prepared from the finger millet in Eastern Himalayan region of India. Forty samples collected from Darjeeling and Sikkim in India were tested for microbiological and analytical characterization. Populations of yeasts and lactic and (LAB) was detected at the level of 7.1 and 5.9 log cfug-1, respectively. Yeasts consisted of *Pichia anomala, Saccharomyces cervisiae, Candida glabrota, Saccharomycopsis fibuligera* and LAB consisted of *Pediococcus pentosaceus* and *Lactobacillus bifermentans* in *Kodo Ko jaanr* smaples. Samples were tested for pathogenic contaminants. Enterobacteriaceae, *Bacillus cereus* and *Staphylocococcus aureus* were not detected in any sample. The P^H, moisture, acidity and alcohol content of the product were 4.1%, 69.7%, 0.27% and 4.8%, respectively. *Kodo Ko Jaanr* was rich in crude fibre. Ash, fat, protein and caloric content remained the same as that of substrate.

Varietal variation for wine making

Wine making is common in certain situations at domestic scale, especially in the hilly and tribal regions. Technology is indigenous and each location has its own technology. Nevertheless, quality of wine is variety-centric. So Shashi *et al*. (2007) from the University of Agricultural Sciences, Bangalore evaluated 4 genotypes for their response to wine–making by using *Saccharomyces cervsiae* var. *ellipsoides*, Chemical composition, nutritional quality, sensory characteristics and acceptability of the wine prepared from 4 varieties of ragi, the variety ML.197 has the highest sodium content, whereas variety ML. 365 had high potassium. P^H was found to be more than 3.0, total soluble solids were in the range of 10.0 - 11.0 and alcohol in the range of 5.3 – 6.9. All the wines had excellent characteristics in terms of appearance, colour, aroma, total acidity and overall acceptability.

Utilization of ragi

Ragi/finger millet is a staple food of millions of people both in India and Africa. In India, it is commonly consumed in the form of ragi balls (*mudde, dumpling*). Unleavened girldle-cooked *roti* with or without seasoning and vegetables. Ragi flour, some times, is blended with wheat flour and made into *chapathis*. Popped ragi ground into powder called *Hurihittu*, mixed with jaggary or sugar, ghee and milk and kneeded into soft balls is an excellent sweetish food with a characteristic aroma. Pancakes are made by mixing ragi flour and blackgram dhal (*Phaseolus mungo*) and consumed with coconut chutney (sauce). Deep-fried, fat-free snakck foods like *chakkuli* and *papads* are made and relished well. Extruded, dehydrated *sandige* and *shavige* (noodle – like) are made. Desert items like *Halwa* (sweet) and *Jamoon* are prepared with white ragi var. *Hamsa*. Even cookies and bread are made, which are acceptable.

Among the modern varieties such as Indaf series were tested for their quality response for making dishes like *Mudde*, *rotis*, *dosa* and salted/

sweet porridge (*umbli*). Varieties like Indaf.3, 8, 11 and 1 were ranked high for sensory characteristics like appearance, colour, aroma, flavour and texture.

An array of weaning foods are made with the use of malts from ragi varieties. Snack foods like tofees, burfis and other starchy preparations are made. Fermented products like country–liquors are made for home consumption. Chocolate flavored malted ragi beverages, snack bars, etc., are the common confectionary items, which are a substitute for branded commercial products like dairy milk chocolate. White ragi is good for making biscuits (white ragi malt mixed with groundnut flour): they could be sweet or salted.

According to Oduori (2005), finger millet had received least research attention in Africa. Colour, water absorption index and diastatic power (criteria for determining malting and brewing qualities) as screening parameters are yet to emerge for evaluating finger millet as main food, snack and malting foods.

Wikipedia reported a basket of foods used in different countries around the world

In *India*, ragi flour is boiled in water and the resultant preparation called *Mudde* is eaten with *sambar* (a local gravy made of dhal, vegetables and spices). Ragi flour is used for making into flat breads, including thick leavened *dosa* and thinner unleavened and *roti* and consumed in Karnataka, Andhrapradesh, Tamil Nadu and Goa in India. Ragi mudde is served with ghee, *Huli/Saru/Sambar* and so on.

In Maharashtra and North Karnataka (India), *Bhakri* also called *bhakar* is a type of flat bread made and consumed. In Goa, ragi is very popular and *Satva*, pole (*dosa*), *bhakri*, *umbli* (a sour porridge) are very common preparations. Nepal: A thick dough made of flour is cooked and eaten. Fermented grain is to make a kind of beer (Jaa) and the mash is distilled to make liquor (*Raks'i*)

In the north-west Vietnam, finger millet is used as a medicine for women when they give birth to a child. A minority of population use ragi flour for making alcohol drink Bacha alcohol which is a good drink for the H'mong minority).

In Southern India, pediatricians recommend finger millet based-foods for infants of six months and above because of its high nutritional content, especially calcium. Home–made ragi malt is one of the most popular infant food even to this day. Ragi malt is mixed with milk and sugar and taken by many as *ragi tea*.

As a traditional food plant in Africa has the potential to improve the nutritional status of food, boost food security, foster rural development and support sustainable land care.

Its straw after threshing of grains is supposed to be a nutritive fodder for livestock, especially for the working animals. After threshing the grain, the residual straw is dried well and stacked properly and fed to the animals throughout the year. In nutritional terms and energy quotient, ragi straw is reported to be superior to that of paddy (rice) straw or sorghum stovers and other crop residues.

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