Research Achievements

Genetic resources

In the past small millets scientists hardly had access to germplasm and worked with a handful of local collections which lacked diversity. Recognizing the importance and conservation and east access to germplasm, AICSMIP established a separate germplasm unit at Bengaluru in 1979. This unit since then has been making efforts to collect as well as pool the available germplasm from various sources and make it available to breeders in the country. Project Coordinating unit is also recognized as National Active Germplasm Site (NAGS) by ICAR/NBPGR and has the mandate to assist in collection, conservation, evaluation and documentation of small millets germplasm in the country. Presently the unit at Bengaluru is maintaining one of the largest collections of more than 10,000 accessions of 6 small millets.

In order to improve the efficiency for utilization of germplasm, core subsets have been formed and made available to breeders working at different centres. Selected germplasm have also been evaluated in the all India testing network and a number of superior accessions were identified and a couple of them have been released for general cultivation in different parts of the country. The exotic collections especially from Africa in finger millet have been largely used in recombination breeding resulting in release of many superior high yielding varieties in many states.

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- Germplasm conserved (10, 183 germplasm in 6 crops), maintained, evaluated, published catalogues and distributed to all research workers for crop improvement. Besides, indigenous and exotic diverse germplasm of all six millets were used by breeders.
- Core set (551 accessions) of germplasm have been formulated in finger millet and evaluated over locations to enhance their utilization in crop improvement.
- A total of 3544 germplasm accessions of six small millets were evaluated and Characterized during the period from 2005-2010.
- Core sets of germplasm have been formulated in foxtail millet, kodo millet, barnyard millet, little millet and proso millet.
- One thousand four hundred and eighty seven new germplasm accessions of various small millets comprising of finger millet (593), foxtail millet (260), kodo millet (405), barnyard millet (95) and little millet (134) were collected and added to the germplasm bank.
- Three germplasm catalogues were published, *viz.* core set of finger millet for 551 accessions, little millet for 902 accessions and barnyard millet for 729 accessions.

Crop improvement

The research in the project was focused to state/regional needs from the point of developing appropriate agro production technology for maximizing production/ productivity. The work is multi-disciplinary and applied in nature. The crop improvement led to the development of high yielding varieties with resistance to blast disease quality fodder, early and medium maturity and white seed in finger millet, resistance to head smut in kodo millet and resistance to shoot fly in both proso and little millets. So far, a total of 272 varieties in 6 small millets have been released in the country.

- More than 272 varieties have been released in different small millets so far

Crop	No of varieties released		Total
	Before 1986	After 1986	
Finger millet (1918-2018)	45	78	117
Foxtail millet (1942-2018)	12	23	32
Little millet (1954-2018)	6	21	20
Proso millet (1954-2018)	8	18	24
Barnyard millet (1949-2018)	4	20	21
Kodo millet (1942-2018)	11	26	31
Total	**86**	**184**	**272**

State wise important /popular varieties in Small millets

Finger millet		
S. No.	State	Varieties
1.	Karnataka	GPU 28, GPU-45, GPU-48, PR 202, MR 1, MR 6, Indaf 7, ML-365, GPU 67, GPU 66, KMR 204, KMR 301, KMR 340, DHFM-78-3
2.	Tamil Nadu	GPU 28, CO 13, TNAU 946 (CO 14), CO 9, CO 12, CO 15
3.	Andhra Pradesh	VR 847, PR 202, VR 708, VR 762, VR 900, VR 936, PPR-2700
4.	Jharkhand	A 404, BM 2, VL-379
5.	Orissa	OEB 10, OUAT 2, BM 9-1, OEB 526, OEB-532
6.	Uttarakhand	PRM-1, PRM-2, VL 315, VL 324, VL-352, VL 149, VL 146, VL-348, VL-376, PES 400, VL-379
7.	Chattisgarh	Indira Ragi-1, Chhattisgarh-2, BR-7, GPU 28, PR 202, VR 708 and VL 149, VL 315, VL 324, VL 352, VL 376, OEB-526, OEB-532
8.	Maharashtra	Dapoli 1, Phule Nachani (KOPN 235), KOPLM 83, Dapoli-2
9.	Gujarat	GN 4, GN 5, GNN 6, GNN-7
10.	Bihar	RAU 8, VL-379, OEB-526, OEB-532
11	Madhya	GPU 28, PR 202, VL 352, VL 376, VL-379

	Pradesh	

Kodo millet		
S. No	**State**	**Varieties**
1	Madhya Pradesh	JK 439, RBK 155, JK 13, JK 65 and JK 48, JK 137, RK 390-25, JK 106, GPUK 3, JK-98, DSP-9-1, TNAU-86
2	Tamil Nadu	KMV 20 (Bamban), CO 3, TNAU 86, GPUK 3, RK 390-25
3	Gujarat	GK 1 and GK 2, GPUK 3, JK-13, JK-65, RK 390-25
4	Chattisgarh	RBK 155 and JK 439, Indira Kodo-1, Indira Kodo- 48, GPUK 3, JK-65, JK-98, Chhattisgarh-2, RK 390-25, TNAU-86
5	Karnataka	GPUK 3, RBK 155, RK 390-25, TNAU-86

Foxtail millet		
S. No.	**State**	**Varieties**
1.	Andhra Pradesh	SiA 3088, SiA 3156, SiA 3085, Lepakshi, SiA 326, Narasimharaya, Krishnadevaraya, PS-4
2.	Karnataka	SiA 326, HMT 100-1 and PS 4,Narasimharaya, SiA 3088, SiA 3156, SiA 3085, DHFt-109-3, PS-4
3.	Tamil Nadu	TNAU 43, TNAU-186, TNAU 196, CO 1, CO 2, CO 4, CO 5, K2, K3, SiA 3088, SiA 3156, SiA 3085, PS-4
4.	Rajasthan	Prathap Kangani (SR 1) and SR 51, SR 11, SR 16, SiA 3085, SiA-3088, SiA-3156, PS-4
5.	Uttar Pradesh	PRK 1 and PS 4, SiA 3088, 3085, Sreelaxmi, Narasimharaya, S-114, SiA 326, PS-4
6.	Uttarakhand	PS 4 and PRK 1, Sreelaxmi, SiA 326, SiA 3088, SiA 3156, SiA 3085, PS-4
7	Bihar	RAU-1, SiA 3088, SiA 3156, SiA 3085, PS-4

Little millet		
S. No.	**State**	**Varieties**
1.	Orissa	OLM- 203, OLM -208, OLM-217, BL-6, DHLM-36-3, DHLM-14-1
2.	Madhya Pradesh	JK-4, JK 8, JK 36, JK-137, BL-6, DHLM-36-3
3.	Andhra Pradesh	OLM 203, JK 8, BL-6, DHLM-36-3
4.	Tamil Nadu	Paiyur 2, TNAU 63 and CO 3,C0-4,K1, OLM -203, OLM -20, BL-6, DHLM-36-3, DHLM-14-1
5.	Chattisgarh	JK 8, BL 6, BL-4, JK 36, JK-137, DHLM-36-3
6.	Karnataka	OLM 203, JK 8, BL-6, DHLM-36-3, DHLM-14-1
7.	Gujarat	GV 2, GV 1, OLM 203, JK 8, BL-6, DHLM-36-3, DHLM-14-1
8.	Maharashtra	Phule Ekadashi, JK 8, OLM- 203, BL-6, DHLM-36-3, DHLM-14-1

Proso millet		
S. No.	**State**	**Varieties**
1.	Tamil Nadu	Co-5, TNAU 151, TNAU 164, TNAU 145, TNAU 202, CO 4, K2, CO 3,CO 2, GPUP 21, GPUP 8 , TNPm-230
2.	Uttarakhand	PRC 1, TNAU 145, 164, 151
3.	Karnataka	GPUP 8, GPUP 21, TNAU 145, TNAU-151, TNAU-164, TNAU-202, TNPm-230, DHP-2769
4	Bihar	BR-7, TNAU 164, 145, PR 18, TNAU-202, TNPm-230
5.	Andhra Pradesh	Sagar, Nagarjuna, CO 4, CO 3, TNAU-151, TNAU-164, TNAU-202, TNPm-230
6	Uttar Pradesh	Bhawna, PRC 1, TNAU 145, 164, 151

Barnyard millet		
S. No.	**State**	**Varieties**
1.	Uttarakhand	VL 172, VL 207, PRJ 1, VL 29, PRS 1, DHBM-93-3
2.	Uttar Pradesh	VL 172 and VL 207, Anurag, VL 29, DHBM-93-3, Kanchan
3.	Tamil Nadu	CO 1, CO 2, VL 181, VL 29, DHBM-93-3

4.	Karnataka	VL 172, RAU 11, VL 181, DHBM-93-3, DHB-93-2
5.	Gujarat	Gujarat Banti- 1, DHBM-93-3, VL-172
6	Bihar	VL Madira 181

Crop production

The package of practices for cultivation different small millets such as time of sowing/ planting, choice of varieties, time and method of application of fertilizers have been developed for different regions of the country. Management practices for aberrant weather conditions for mitigating early, mid and late season drought have been worked out. Remunerative cropping systems involving different pulse crops in millet for different regions have been evolved.

Nutrient management

- Application of Zn @ 12.5 kg ha^{-1} in Odisha and boron @ 5 kg ha^{-1} in Jharkhand based on soil test were essential for maintaining higher productivity in finger millet.
- Application of enriched Vermicompost (VC) and chullu cake with *Azatobacter*(to supply 50% N from each source)for barnyard millet in Uttarakhand, whereas vermicompost enriched with biofertilizers *(Azospirillumbrasilense*and *PSB).*to supply 100% N for kodo millet in Madhya Pradesh, and Similarly FYM and Vermicompost (*Azospirillumbrasilense*and *PSB) f*or foxtail in A.P. are better options for organic small millet production.
- Application of poultry manure to supply 100% N or combination of poultry manure and oil cakes to supply 50% N from each source were found promising for organic finger millet production in southern Karnataka.
- Application of 3.75 t FYM ha^{-1} plus gypsum @200 kg ha^{-1} and balance of P through rock phosphate and 50% N through oilcakes as top dressing was found to maximize productivity of organic finger millet in Jharkhand and Tamil Nadu.
- For low fertility conditions varieties Srilakshmi and Krishnadevaraya (foxtail), DPS-439 and RBK-155 (kodo), RLM-43 and OLM-208 (little millet) and PRJ-1 (Barnyard) were found suitable.
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- SRI method of transplanting 15 days old one seedling per hill of finger millet is a better option for enhancing the productivity of finger millet under irrigated conditions in Karnataka
- Establishing finger millet crop by square planting at 22.5 cm with 2-3 seedlings per hill was a better option under rainfed conditions at Bangalore and Kolhapur
- Planting in ridges/furrows was a better practice for higher grain yield in finger millet under rainfed condition in Chattisgarh state.
- Application of 75% RDF to Ragi followed by rice-*Sunhemp*-ragi cropping system is recommended for higher finger millet grain yield under irrigated conditions in Karnataka
- Application of poultry manure or pressmud to supply 150 kg N/ha is remunerative for organic finger millet production practice to sustain higher productivity under irrigated condition at Mandya.
- Application of recommended dose of FYM (7.5 t /ha) and 75 per cent RDF along with treating seeds with bio-fertilizers (*Azospirillumbrasilense* +*Bacillus magatherium* + *Psuedomonasfluroscence*is a better practice for higher productivity at Kolhapur region.

- Transplanting of pigeon pea with 40-45 day old seedlings raised in polybags as an inter crop in finger millet in 2:8 row ratio is remunerative practice in Bastar region of Chattisgarh
- Finger millet and Barnyard millet are better choices among small millets under saline sodic soils
- Mechanized harvesting of finger millet through Shrachi make TR 120 engine reaper is found to be cost effective and time saving.
- Soil application of *Trichodermaviride* @ 2.5 kg/ha. Either individually or in combination with *Pseudomonas fluorescens* (each @ 1.25 kg/ha) mixed with 60-65 kg compost, incubated for 10 days and applied at the time of first inter cultivation or hand weeding (25 to 30 days) to manage foot rot of finger millet growing states.

Cropping systems

- Foxtail millet and pigeon pea intercropping (5:1) was found remunerative cropping system in A.P.
- Sequence cropping of cluster bean /cowpea in *kharif* followed by finger millet in *rabi*or vice-versa was better choices for maintaining higher productivity besides sustaining soil health in Odisha.
- Finger millet–maize/groundnut two years crop rotation for Karnataka, whereas kodo- soybean and kodo-niger for M.P. were found remunerative.
- Finger millet+soybean crop mixture (90:10) in *kharif* followed by oats /barley in *rabi* were remunerative cropping system for mid hills of Uttarakhand.
- Intercropping of foxtail + castor in 5:1 or 8:1 ratio is recommended for black cotton soils of Andhra Pradesh
- In skeletal soils of Dindori region (Madhya Pradesh), Kodo/ little + pigeonpea inter cropping (2 to 4:1) was a remunerative system
- Foxtail millet – chickpea crop sequence is remunerative in black cotton soils instead single crop or keeping the land fallow during *kharif* in Nandyal region of AP.
- Little millet followed by horsegram is remunerative cropping sequence in Chattisgarh state.

Crop Protection

Plant Pathology

- New sources of resistance viz. GE 4440, GE 3090, GE496 and GE 4449 to blast in finger millet were identified.
- Finger millet cultivars GPU 28 and GPU 48 stable sources of resistance in improved and adapted cultivars, such as identified.
- In organically grown finger millet, two sprays of *Pseudomonas fluorescens* @ 0.2% (first spray at 50% flowering followed by second spray 10 days later) were found effective in controling of neck and finger blasts.
- In the management of blast disease of finger millet, treating seeds with *Pseudomonas fluorescens*@ 6g/kg followed by two sprays @ 0.3% during 50% flowering to grain filling was recommended as an alternative to spray of edifenphos (0.1%).
- Tricyclazole @ 0.6gL^{-1} as spray at first incidence of foxtail millet blast (Nandyal) was effective in reducing the incidence of blast in foxtail millet and improving yield.
- Treating kodo millet seeds with carboxin (2gkg^{-1}) was superior in controlling head smut besides increasing grain yield at Rewa.
- Seed treatment with carbendazim @2gkg^{-1} seed minimized grain smut in barnyard millet and enhanced grain yield at Ranichauri.

- Seed treatment with carbendazim at 2gkg^{-1} followed by two sprays @ 0.05% effectively controlled sheath blight of kodo millet at Rewa.
- Seed treatment with talc formulated P.fluorescens @ 10 g/kg is ideal for the control of sheath rot of kodo millet caused by Sarocladiumoryzae
- Seed treatment with Validamycin @ 0.1% or Hexaconazole @ 0.2% and one need based spray with either of the chemicals control banded sheath blight of kodo millet caused y R. solani.
- Seed treatment with Hexaconazole @ 0.2% or Validamycin 0.1% controls banded sheath blight of little millet caused by R. solani

Entomology

- An IPM package involving clean cultivation, early sowing with higher seed rate (one and a half times) followed by trapping the adult flies with fish meal traps was found effective in mitigating the menace of shootfly in little, barnyard, kodo and proso millet.
- Spraying of 1500 ppm neem/ azadirachtin at 7 DAS and 15 DAS is effective in controlling shoot fly.
- Resistant sources for Banded sheath blight in Little millet were RLM 224, OLM 203, TNAU 176, 178 and RLM 4-1.
- Resistant sources Banded sheath blight in Kodo millet were RPS 594, RPS 630, KOPKN 8, 14, 20 and JK 13

Crop physiology

- In finger millet, PR-202 was more drought tolerant than GPU-28 due to radiation reflectance mechanism and wax accumulation.
- Finger millet accessions MR-6, GE-1034, GE-3434, GE-3457, GE-619, GE-4999 were high root biomass types suitable for drought condition
- The high TDM accessions and grain yield identified over the years were MR-6, L-5, GE-449, GE-1013, GE-1293, GE-1687, GE-5192, GE-5252, GE-4995, and GE-4683.
- GPU-67, HR-911 and L-5 were high harvest index types. GPU-67 found to be ideal plant type with short plant stature, non-lodging, high photosynthetic rate and leaf thickness.
- In finger millet, PR-202 was more drought tolerant than GPU-28 due to radiation reflectance mechanism and wax accumulation.
- Foliar application of $ZnSO_4$ (0.5%) enriches the grain zinc content by 20 percent while soil application of zinc (12.5 kg.ha-1) increases the grain yield by 10.2 percent.

Grain processing and Value addition

- Technologies of value addition to small millets developed include: malted flour from finger millet, infant food, decorticated *ragi* (*ragi*rice), flakes from small millets, expanded *ragi*,*ragi* seed coat based foods, extruded foxtail millet, ready to eat snack (muesli) from flaked millets, health beverage from malted finger millet and entreal foods
- Lab scale prototype millet mill (10-15kgh^{-1}) for grain processing was developed and installed in PC unit.
- Foxtail and proso millet are rich in protein (> 15%). The carotenoid contents was found to be very high in proso (> 500µg) and foxtail millet (> 600 µg) as compared to finger millet (< 100µg).

- Seed coat phenolics of finger millet were found to inhibit pancreatic amylase and glucosidase activities, making the finger millet hypoglycemic.
- Finger millet had high anti-oxidant activity compared to other millets.
- Germination and malting of millets decreased the polyphenol content and improved bio-availability of minerals upto 75 %.
- Foxtail and proso millet are rich in protein (> 15%). The carotenoid contents was found to be very high in proso (> 500µg) and foxtail millet (> 600 µg) as compared to finger millet (< 100µg).
- In animal feeding trials, it was observed that regular consumption of finger millet minimized the risk of cataract formation in rats.

Transfer of Technology

- Frontline demonstrations (2005 to 2011) were conducted across the country in 1765.04 hectares covering 5160 farmers. The improved technology resulted in yield increase of 23-210% in different millets over farmers' practices.
- In FLD's the productivity of finger millet was highest at Tamil Nadu (3030 kg ha^{-1}), followed by Karnataka (2592 $kgha^{-1}$) and Jharkhand (2355 $kgha^{-1}$).
- Improved intercropping demonstrations involving pigeonpea showed productivity enhancement from 31 to 174% in finger millet and pigeonpea, respectively over farmers' practice.
- Sole crop of foxtail millet with improved production package demonstrations in Andhra Pradesh and Karnataka gave 41 per cent higher yield (2988 $kgha^{-1}$) over farmer's practice (2179 $kgha^{-1}$).
- Intercropping of pigeonpea with foxtail millet (1:5) was observed to be remunerative practice than farmers' practice of sole cropping in Andhra Pradesh.
- In kodo millet the recommended package gave 61% higher grain yield (1742 $kgha^{-1}$) over farmers' practice (1145 $kgha^{-1}$) in FLDs in MP.
- Pigeonpea and kodo millet inter cropping (1:2) enhanced productivity of the system by 91 per cent over farmers' practice (sole crop).
- In sole crop demonstrations in little millet in Karnataka, Madhya Pradesh, Tamil Nadu and Odisha improved practice gave 70% higher yield (1202 $kgha^{-1}$) over farmers' practice (732 $kgha^{-1}$).
- Inter cropping of little millet and pigeonpea (2:1) was a remunerative practice and enhanced productivity of the system over farmers' practice by 140% in MP.
- In barnyard millet improved practice demonstrations gave 95% increase in productivity (1457 $kgha^{-1}$) over farmers' practice across 371 farmers in Uttarakhand and Uttar Pradesh.
- Improved practice demonstrations in sole proso millet crop gave 67% higher yield (2000 $kgha^{-1}$) over farmers' practices (1200 $kgha^{-1}$) in Uttar Pradesh.

Farm Machinery/equipment introduced:

- Mechanized Finger millet harvesting through Shrachi make TR 120 engine reaper