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Current Scenario of Crop Improvement of Finger Millet [*Eleusine coracana* (L.)] in India: A Review

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ABSTRACT

Finger millet [*Eleusine coracana* (L.) Gaertn.] is an ancient and important millet crop of India. The crop is predominantly grown as rainfed crop in the peninsular Indian states. The crop has shown numerous advantages over major cereals in terms of stress adaptation, nutritional quality and health benefits. Finger millet is highly self pollinated crop. Hybridization in finger millet is difficult due to small cleistogamous florets. Presently hot-water treatment followed by contact method of crossing is widely used across institutes for generating breeding populations. The availability of versatile male sterile systems could enhance hybridization in the crop. A novel male sterile line PS1, developed and maintained just by growing in isolation and thus improving its accessibility for hybridization. The varieties in finger millet released over a period of time were by adapting hybridization followed by selection. Till now, a total of 141 varieties of finger millet have been developed and released in the country. Finger millet occupies a prime position among millets. Realizing the nutritional importance, it is now in high demand. Knowledge on the improved production strategies right from selection of high yielding varieties to market led extension and extensive usage at national and global level has a vital role. The review, therefore, provided detailed information on hybridization methods, crop improvement and details of recently released varieties and their adaptation in finger millet.

Key words: Crop improvement, Finger millet, Floral morphology, Hybridization methods, Wide hybridization.

Millets, the nutritious cereals, are ancient foods known to human beings are often referred to as the resilient crops of the future due to wider adaptability to diverse agro ecological conditions and ability to support sustainable diets. In world, finger millet is one such small millets and ranked fourth in importance among millets after sorghum, pearl millet and foxtail millet (Upadhyaya *et al*., 2007). Finger millet is an annual herbaceous cereal crop with nutraceutical value. It is a crop of antiquity with great historical, cultural and nutritional importance. It is highly adapted to the semiarid tropics and is grown as a staple food crop in Asia and Africa. Globally, it is the sixth most important crop among cereals in terms of production and it contributes about 12% of the total millet area. Its origin dates back to 5,000 years in western Uganda and the Ethiopian highlands. India is considered a secondary center of diversity for finger millet as its cultivation can be traced to 3,000 BC in the Western Ghats (Hilu and DeWet, 1976). The crop is highly self-pollinated and allotetraploid (AABB) with chromosome number 2n = 4x = 36. In India Finger millet is cultivated over 0.97 million hectares with 1.68 mt production and 1662 kg/ha productivity during 2019-2020 reported by Dept. of Economics and Statistics, DAC and FW, Government of India, New Delhi. Finger millet is grown in more than 25 countries in eastern and southern Africa and across Asia from the Near East to the Far East. The major finger millet producing countries are Uganda, India, Nepal and China. The major finger millet growing states are Karnataka, Tamil Nadu andhra Pradesh, Orissa, Maharashtra, Uttar Pradesh, Bihar, Gujarat and Madhya Pradesh.

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Nutritional Point of view finger millet is considered as “Super Cereal” which is rich in minerals and micronutrients (National Research Council, 1996). Kazi *et al* (2022) reported finger millet land races are potential source of nutrients. Finger millet has been identified as one of the “future smart food crops” by FAO (Li and Siddique, 2018) because of its nutrient-dense and climate-resilient features; moreover, it can produce a reasonable yield at a relatively low cost of cultivation (Gupta *et al*., 2017). Finger millet grains are highly resistant to pest attacks and can be stored for long, (Mgonja *et al*., 2007) which makes it a valuable crop particularly for famine prone areas and provide nutritional support to countries in the developing world (Mgonja *et al*., 2007; Gupta *et al*., 2017). Although grown under dry lands, it provides an assured harvest, thus making it indispensable in speciûc ecosystems. The crop provides food grain and straw which are valued animal feed, especially in the rainfed areas and hills.

Considering the increased demand for finger millet for food purposes and decreasing area due to competing crops, there is a need for genetic enhancement of finger millet productivity. Analysis and exploitation of existing genetic variability is a short-term strategy for developing improved cultivars for meeting immediate requirement of the farmers and the end-users. Exploitation of variability created by hybridization through recombination breeding is the major approach adopted in finger millet improvement programs. Often, a plant breeder/researcher is confronted with the task of handling segregating populations derived from a large number of crosses. Early elimination of poor crosses helps in efficient utilization of land, time and human resources and allows handling of reasonably large segregating populations derived from a few promising crosses (Krishnappa *et al.,* 2009).

Parental diversity based on morphological traits and their geographical origin has been used as criteria for selecting the parents for making crosses to generate and exploit useful variability. While crossing the best with best and hoping for the best but misconstruing the potential (White-house, 1969), parents of different geographical and agro-ecological origin (though likely to harbor a different set of gene complexes) often fail to result in productive crosses on account of same level of mean expression (Chahal and Gosal, 2002). Studies on assessing dependable criteria for identifying potential parents for use in recombination breeding are limited in regionally important food staple crops such as finger millet.

Floral morphology and anthesis in finger millet

Finger millet inflorescence is a panicle, made up of spikes. Each spike has many spikelets arranged in sequence and every spikelet contain 4–10 florets. Most florets in the finger millet inflorescence are perfect flowers except few terminal ones. In each spike, spikelet open from the top to down-ward, while in each spikelet florets open from bottom to top and one floret in the spikelet opens per day. The florets are covered by a pair of scales known as palea and lower flowering glumes known as lemma. Two little scales known as lodicules are present near the base of the ovary. Florets have unilocular bicarpellary gynoecium with superior ovary and single ovule, while the androecium has three hypogynous stamens. The androecium completely surrounds the stigma, which ensures self-pollination (Gupta *et al.* 2012). There is a little chance of cross-pollination in finger millet as feathery stigma is covered by dehiscing anthers upon opening of florets (Dodake and Dhonukshe, 1998). The reported natural crossing estimates generally do not exceed 1% in finger millet (Rachie and Peters, 1977).

The better understanding of the anthesis behavior and subsequently to develop a efficient crossing technique, a study was conducted with USB microscope using “Time Lapse method” where the whole process of anthesis was captured in sequence of photographs (Fig 1). The sequence of photographs recorded gave better understanding about anthesis behavior. In finger millet, anthesis generally takes place early in the morning (2 am to 5 am) and varied among the fingers. Within finger, the flowering initiates from top and proceeds downwards and within spikelets the order of opening is from bottom to top. It was also observed that high humidity and low temperature favours chasmogamy while high temperature and low humidity favours cleistogamy. For effective hybridization, it is advised to raise the parental lines during *kharif* season for obtaining more hybrid seed (Anonymous, 2016).

Hybridization methods

Floral morphology, tiny florets and anthesis behavior are the major hindrance in recombination breeding through hybridization in finger millet. Manual emasculation of florets is practically very difficult in finger millet; therefore, contact method of hybridization is followed by breeders. Female and male parent panicles are tied together by intertwining the fingers of male panicle inside the female panicle. For protection and exclusion of external pollen, the crosses are covered with butter paper bag. Seeds are harvested only from female genotype, which all need to be grown in next season for identification of hybrid plants. Very few hybrid seeds are recovered in contact method. Inter-varietal hybridization using contact method (Ayyangar, 1934) is the simplest and easiest way. For the successful hybridization, genotypes having dominant character such as pigmentation on nodes have been used as male parent (Gupta, 2006), which helps in the identification of true hybrids in the F_1 generation.

Hot water emasculation is alternate method, where the female panicles in appropriate stage are immersed in hot

Fig 1: Antesis studies in finger millet.

water at a temperature of 48-52°C for 5 minutes for effective emasculation (Raj *et al.* 1984). The crossing technique following hot water emasculation is presented in Fig 2. Temperature requirements may vary with the location and growing conditions in this method. Temperature and humidity induced flower opening is also reported. In this method, a polythene bag of size 7.5 cm × 10 cm lined with moist filter paper is used to cover the panicle at appropriate stage and plugged with absorbent cotton wool. Due to high humidity, the anthers emerge out of florets without shedding pollen. Pollen from male genotype is collected by tapping the bag and is dusted on the emasculated panicle.

Genetic male sterility (GMS) is also reported in finger millet. This has been used as one of the techniques for enhancing hybridization and creation of variability. The GMS line is known as 'INFM 95001' which was jointly developed by ICRISAT at Matapos, Zimbabwe and Kano, Nigeria and the Department of Agronomy, University of Nebraska, USA (Gupta *et al.* 1997). However, it could not be utilized for hybridization in finger millet due to maintenance problem in GMS. A partial GMS line (PS 1-IC0598201; INGR14015) in GPU 28 varietal background is identified, but its practical utility is also limited due to varying levels of sterility/fertility in different locations and genetic backgrounds (Gowda *et al.* 2014).

The partial male sterile (PS 1) and virescent (accession no. GE 1) mutants isolated at the Project Coordinating Unit (Small Millets), ICAR-AICRP on small millets, Bengaluru and was characterized. PS1 is an EMS generated mutant, sets approximately 10% seeds upon bagging, 20% under open pollination and up to 49% in controlled crossing. Genetic study revealed the monogenic recessive nature of the trait and segregation in F_2 and F_3 generations indicated the prevalence of gametic selection. Pollen germination under Florescence microscope proved that disruption in both pollen germination and pollen tube growth is the cause of partial male sterility. The identification of hybrid derivatives from the pool of progeny plants can be done only after seed set thus requiring more space and time which restricts the breeder to handle large number of crosses. Using PS 1 heterosis level was assessed in the hybrids generated with a set of 46 genotypes (28 improved varieties from different states of India and 18 elite germplasm from African and Asian countries) during 2014 summer and *kharif* seasons. Relationship between heterosis and parental divergence based on 18 morphological traits and 16 SSR markers were also examined.(Manjappa *et al.*, 2019).

Introgression of virescence seedling marker with PS1 allows identification of F_1's at seedling stage itself and thus enabling the breeder to handle large number of crosses in less space. In this regard a novel virescent mutant (GE1) developed at AICRP on small millets, GKVK, Bengaluru was characterized for its utility in hybridization. Virescence is a chlorophyll deficient trait controlled by a recessive gene, express at seedling stage and subsequently shows progressive reversion to normal green colour. In order to enhance recombination breeding in the crop thirty-three diverse male sterile-virescent lines were developed (Manjappa *et al.*, 2022).

Totally 12 different partial sterile lines, 5 virescence lines and 7 virescence with PS lines were developed. Among these ten lines were selected for crossing with different released varieties and germplasm accessions for evaluation.

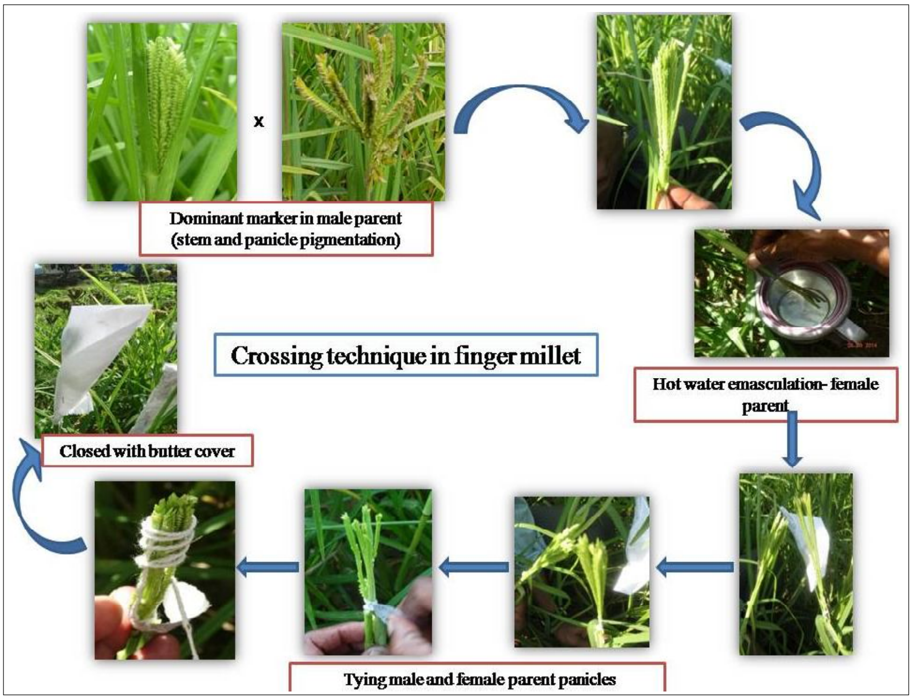

Fig 2: The crossing technique following hot water emasculation in finger millet.

The crop needs extensive studies on the use of gametocides along with search for other stable male sterile systems and mechanisms like protogyny (Oduori and Kanyenji, 2007) for effective utilization of heterosis in finger millet.

Among various emasculation and pollination techniques, contact method is widely used technique for hybridization, the technique has a success rate of 2-3% while remaining 95-98% are self seeds and therefore the hybridization technique requires morphological or molecular marker for identification of true F_1s (Ganapathy *et al*., 2022). Plant Pigmentation at Panicle and nodal region is a dominant marker and is present in 30% of the germplasm and is presently widely used for identification of true F_1s.

Yield enhancement through wide hybridization

Temporal and spatial isolation of finger millet in two different continents, *i.e*., Africa and Asia (particularly India) for over 5000 years led to the emergence of two morphologically and genetically distinct gene pools. A few systematic studies comparing the diversity in the African and Indian collections revealed many differences related to yield components and disease resistance. Most Indian accessions had semi-compact or compact ears (race vulgaris) and higher mean values for finger length, finger width, grain yield potential, ear weight, total biomass and fodder weight and leaf number. The African accessions have more diversity for ear types ranging from open to fist shaped (race plana and compacta). They also showed tall stout plant stature, long broad flag leaf, long narrow finger, higher number of spikelets, more florets per spikelet, small and long glumes, poor thresh ability, low harvest index and late maturity (Naik *et al.* 1993). The African germplasm was also found to have other desirable characters like high initial vigor, large ears, high grain density, broad dark green leaves and resistance to blast disease (Seetharam, 1998).

The introgression of desirable traits from African germplasm into Indian adapted genotypes is the most significant aspect of finger millet improvement in India (Gowda *et al*. 1986). The Indo-African crosses have provided the real backbone for breaking the grain yield barriers in the improvement of finger millet. It helped in increasing finger millet productivity by more than 50% in Indian southern states, Karnataka (Seetharam, 1998) and Tamil Nadu (Nagarajan and Raveendran, 1983). Further improvement in finger millet productivity and quality is possible through identification of heterotic pools from large germplasm collection. This activity is lacking in finger millet breeding across the globe; however, identification of diverse heterotic pools which can cross readily will make the crop more competitive in comparison to major cereals for grain yield. Although homozygous parental lines development is easy in finger millet, complete homozygosity can be achieved through doubled haploid technology (Forster and Thomas, 2005). Interspecific heterotic groups can be successfully used in breeding programs for genetic improvement (Ramya *et al*. 2018). These techniques should be investigated and integrated into breeding programs. To create novel variability and diversification of cultivated gene pool of finger millet, efforts were made to cross cultivated lines with wild species *viz., E. indica, E. Africana, E. jaegari* and *E. tristachya.* GE-1 is a germplasm accession express yellowish green leaf/ virescence from 3rd leaf stage till 30-35 days of sowing and is clearly distinguish from the normal green phenotype. Using GE 1 as female parent, successful interspecific hybrid was developed with wild species *E. jaegari*. F_1 resembled mostly traits of wild phenotype and also resulted in partial seed set (<10%). The seeds were harvested and are advanced to F_3 generation. Backcrosses are being attempted with cultivated types for development of diverse and improved plant types for its use in further breeding programmes (Ganapathy *et al*., 2022).

Crop improvement efforts in India

Plant breeding is the science driven creative process of developing new plant varieties that goes by various names including cultivar development, crop improvement and seed improvement conventionally by selective mating and hybridization. Early finger millet breeding was largely confined to India, particularly in southern states of Tamil Nadu, Karnataka and Andhra Pradesh. Later, it spread to other Indian states such as Gujarat, Maharashtra, Orissa, Bihar and Uttarakhand. The yield levels were very low, due to lack of inputs, poor soil fertility, rainfed farming, low yielding cultivars and lack of improved agronomic practices. Initial breeding efforts in finger millet were limited due to its self pollinating nature. Development of emasculation and pollination techniques created the opportunity to improve the crop and create new hybrids. Later, various breeding approaches such as pure line selection, recombination breeding and mutation breeding were extensively used for the genetic improvement of finger millet.

Hybridization and recombination breeding is difficult in finger millet since emasculation and cross pollination are tedious due to small florets and low success of emasculation techniques. Mutation breeding is the only alternate for crop improvement in plants having small size florets. Mutation breeding was effectively used in finger millet for the development of early-maturing types, generation of polygenic variability and development of complete and partial male sterile lines. Physical, chemical and combinations of mutagens were used for this purpose.

Small millets improvement efforts have been in progress since the beginning of the 20th century (Seetharam, 1998). But, the launching of coordinated crop improvement programs during late 1950s and 60s has contributed significantly by way of developing new superior varieties and concomitant production and protection technologies in all small millets. The release of improved varieties and production packages for general cultivation has helped in 3-fold increase in grain productivity in the country. The small millets have been the last priority crops in the agriculture developmental agenda in the country. Finger millet among

Table 1: The list of recently released finger millet varieties and their adaptation.

Variety	Developed by	Area of adoption	Salient features
Phule Nachani 1 (KOPN 235)	Zonal Agricultural Research Station, Shenda Park, Mahatma Phule Krishi Vidyapeeth, Rahuri, Kolhapur, Maharashtra	Maharashtra	Suitable for sub mountain and Ghat zone of Maharashtra, yield 25.0-26.0 q/ha., maturity 115-120 days, resistant to blast.
VL Mandua 352 (VL 352)	ICAR- Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand	All finger millet growing states except Tamil Nadu and Maharashtra	Suitable for all Ragi growing areas of country, yield 33.0-35.0 q/ha, maturity 95-100 days, moderately resistant to blast.
Arjuna (OEB-526)	All India Coordinated Small Millet Improvement Project, Centre for Pulse Research, Orissa University of Agriculture and Technology, Berhampur, Odisha,	Odisha, Bihar, Chhattisgarh, Karnataka and Tamil Nadu	Suitable for Odisha, Bihar, Chhattisgarh, Karnataka, Tamil NaduYield 25.0-26.0 q/ha, maturity110-115 days moderately resistant to leaf, neck and finger blast diseases.
GNN-6	Hill Millet Research Station, Navasari Agricultural University, Waghai, Gujarat	Gujarat	Suitable for Gujarat region, yield 28.0-30.0 q/ha, maturity 120-130 days, moderately resistant to leaf blast and finger blast.
GN-5	Hill Millet Research Station, Navasari Agricultural University, Waghai, Gujarat	Gujarat	Suitable for Gujarat region, yield 25.0-27.0 q/ha., late maturing, white colour seed maturity120-130 days, moderately resistant to leaf and finger blast.
VL Mandua 348	ICAR- Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand	Uttarakhand	Suitable for organic cultivation, yield 18.0-20.0 q/ha under organic conditions, dwarf in stature (87 cm), light copper grains maturity104-112 days, resistant to neck and finger blast and tolerant to lodging.
Dapoli - 2 (SCN - 6)	Agricultural Research Station, Dapoli, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli Dist. Ratnagiri, Maharashtra	Maharashtra	Suitable for Konkan region of Maharashtra., yield :25.0-27.0 q/ha., high yielding, rich in iron and calcium, maturity 118-120 days, moderately resistant to blast, tolerant to aphids and *Spodoptera litura.*
CO 15	Centre of Excellence in Millets, Tamil Nadu Agricultural University, Athiyandal, Tiruvannamalai District, Tamil Nadu	Tamil Nadu	Suitable for Tamil Nadu region, Yield 29.0 under rainfed and 34.0 under irrigated conditions, highly responsive to nitrogenous fertilizer, nutritionally rich grain and fodder, possesses consumer preferred bold and copper red grainsmaturity115-120 days, non-lodging, resistant to leaf, neck and finger blasts.
KMR 340 (White seeded variety)	V.C. Farm, Mandya, University of Agricultural Sciences, Bangaluru, Kamataka	Karnataka	Suitable for irrigated and rainfed parts of Karnataka, yield 35-40 q/ha., straw: 5-7 t/ha., white ragi variety, specially for confectionary purpose, maturity 95-100 days, resistant to blast and blight diseases, tolerant to stem borer and aphids.
GNN 7	Hill Millet Research Station, Navasari Agricultural University, Waghai, Gujarat	Gujarat	Suitable for Gujarat region, yield 25.0 q/ha., high mineral matter (%), crude fibre, calcium, phosphorous and good amount of protein, fat, carbohydrats and magnesium, maturity 123-128 days.
VL Mandua 376 (VL 376)	ICAR- Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand	All Ragi growing areas of country	Suitable for all ragi growing areas of country, Yield 29.0- 31.0 q/ha., responsive to fertilizer, maturity103-109 days, moderately resistant to blast
DHFM-78-3	Agricultural Research Station,	Karnataka	Suitable for cultivation in Agro-climatic

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	Hanumanamatti, University of Agricultural Sciences, Dharwad, Karnataka		Zone - 3 and 8 of Karnataka state, Yield 30-35 q/ha, suitable for contingency planting, Maturity 115-120 days, resistant to finger and neck blast.
VL Mandua 379 (VL 379)	ICAR, Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand	Uttarakhand, Bihar, Jharkhand and Madhya Pradesh	Suitable for rainfed *kharif* ecology, fertilizer responsive, Yield 31-35 q/ha, Maturity107-109 days, resistance to neck and finger blast, tolerant to ear head caterpillar incidence.
Chhattisgarh Ragi-2 (BR-36)	S G College of Agriculture and Research Station, JagdalpurIndira Gandhi Krishi Vishwavidyalaya, Raipur Chhattisgarh	Chhattisgarh	Withstand better under water stress conditions, Yield 34-36 q/ha, responsive to nitrogen fertilizer, Maturity 115-118 days, non lodging, tolerant to stem borer and other major pests.
VL Mandua 380	ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand	Uttarakhand	Suitable for Uttarakhand hills under rainfed *kharif* ecology, yield 23.79 q/ha, maturity 116-118 days, higher calcium content (322.5 mg/100 g), moderately resistant to neck and finger blast, no major pest infestation.
Vegavathi (VR 929)	Agricultural Research Station, Vizianagaram, Acharya N.G. Ranga Agricultural University andhra Pradesh	Andhra Pradesh	Suitable for rainfed *kharif* season, average grain yield 36.1 q/ha, fodder yield 72.0 q/ha, maturity 115-120 days, highly resistant to brown spot, banded blight, foot rot and *Cercospora* leaf spot. Resistant to leaf, finger and neck blast, low incidence of grass hopper, *Myllocerus* weevil and ear head caterpillar, higher Zn content (199.1%) with high Fe, Ca, protein content, dietary fiber and low in tannin content.
GN 8	Hill Millet Research Station, Navasari Agricultural University, Waghai, Gujarat	Gujarat	Suitable for cultivation during *Kharif* season, yield average seed 30.7 q/ha, maturity 105-110 days, erect and non-lodging plant type, moderately resistant to leaf, neck and finger blast as well as foot rot disease under tolerant reaction to pests like stem borer and aphids.
Tirumala (PPR 1012)	Agricultural Research Station, Perumallapalle, Acharya N.G. Ranga Agricultural University Andhra Pradesh	Andhra Pradesh	Suitable for irrigated and rainfed conditions in *kharif*, average seed yield 20.0-25.0 q/ha under rainfed conditions, 30.0-35.0 q/haunder irrigated conditions, maturity 115-120 days, highly three types of blast *viz*., leaf blast, neck blast, finger blast moderately resistant to leaf blight and banded blight; resistant to grass hoppers and ear head caterpillars.35.0
Gowthami (PR 10-45)	Agricultural Research Station, Peddapuram, Acharya N.G. Ranga Agricultural University Andhra Pradesh	Andhra Pradesh	Suitable for rainfed *kharif* and *rabi* season, average seed yield: 36-38 q/ ha, maturity: 117 days, moderately resistant to leaf blight, banded blight, leaf blast and neck blast diseases, moderately resistant to grass hoppers and ear head caterpillar,

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			high calcium (341.5 mg/100g) and zinc (26.5 ppm).
KMR- 630	V.C. Farm, Mandya, University of Agricultural Sciences, Bengaluru Karnataka	Karnataka	Suitable for rainfed *kharif* and late *kharif* seasons, average seed yield: 35-40 q/ha, maturity: 95-100 days, resistant to neck and finger blast disease, tolerant to stem borer, aphids, grass hopper and ear head caterpillar.
VR 988	Agricultural Research Station, Vizianagaram, Acharya N.G. Ranga Agricultural University Andhra Pradesh	Andhra Pradesh	Suitable for rainfed condition in *kharif* and irrigated condition during *Rabi* seasons, average seed yield: 30-32 q/ha, maturity: 105 days, resistant to leaf, finger and neck blast, foot rot and moderately resistant to blight diseases, resistant to grass hoppers and ear head caterpillars, high calcium (428.3 mg/100g), iron (58 ppm) and zinc (44.5 ppm) content.
KALUA (OEB 532)	Centre for Pulses Research, Berhampur; Orissa University of Agriculture and Technology, Berhampur, Odisha, Bhubneshwar, Odisha	Odisha	Suitable for rainfed uplands during *kharif* and irrigated during summer seasons, average seed yield: 17-18 q/ha, maturity:1 10 days, resistant to leaf and neck blast, moderately resistant to finger blast diseases, resistant to myllocerus weevil, ear head caterpillar, stem borer and grass hoppers.
CFMV 2 (FMV 1118) (GN-9/Gira) (Biofortified variety)	Hill Millet Research Station, Navasari Agricultural University, Waghai, Gujarat	Andhra Pradesh, Chhattisgarh, Gujarat, Maharashtra, Odisha	Suitable for rainfed condition during *Kharif* season, suitable for rainfed condition during *Kharif* season, average grain yield 29.5 q/ha, dry fodder yield 8.6 t/ha, medium maturity (119-121 days), rich in calcium (454 mg/100 g), iron (39.0 ppm) and zinc (25.0 ppm), resistant to leaf blast, foot rot, brown spot, grain mould. Resistant to leaf blast, foot rot, brown spot, grain mould and moderately resistant to neck blast, finger blast and banded blight. It is Superior in respect to Ca, Zn, crude fiber and mineral matter.
CFMV 1 (Indravathi) (FMV 1116) (VR 1101) (Biofortified variety)	Agricultural Research Station, Vizianagaram, Acharya N.G. Ranga Agricultural University Andhra Pradesh	Andhra Pradesh, Tamil Nadu, Karnataka, Puducherry, Odisha	Suitable for rainfed condition during *kharif* season, average grain yield 3.11 t/ha, dry fodder yield 8.4 t/ha, medium maturity (110-115 days).Multi disease (Finger blast, Neck blast, Banded blight and Foot rot) and multi pest resistant (Shoot aphids, stem borer, grass hoppers). It has 58.3 mg/kg iron and 44.5 mg/kg content. Rich in calcium (428.3 mg/100 g) and anti-oxidant content (92.0 mg/100 g).
VL Mandua 378	ICAR - Vivekananda Parvatiya Krishi Anusandhan Sansthan. Almora, Uttarakhand	Uttarakhand	It is moderately resistant to neck and finger blast, semi compact ear heads. has higher calcium (361 mg/100 g) and iron (4.5 mg/100 g). Suitable for rainfed organic ecology, average grain yield 21

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			q/ha, medium maturity (114 days), high calcium (361 ppm) and iron (45 ppm), moderately resistant to neck and finger blast.
VL Mandua 382	ICAR - Vivekananda Parvatiya Krishi Anusandhan Sansthan. Almora, Uttarakhand	Uttarakhand	Suitable for rainfed organic ecology, average grain yield 22.8 q/ha, medium maturity (112 days), white coloured grains, white coloured grains, has higher calcium (340 mg/100g) and protein content (8.8%) has very low tannin content suitable for processing industry. Got higher consumer acceptability and fetch better price to the farmers.
CFMV-3 (Ekvijay)	Hill Millet Research Station, Navasari Agricultural University, Waghai, Gujarat	Andhra Pradesh, Tamil Nadu, Telangana, Maharashtra and Gujarat	Suitable for profuse tillering, highly suitable for rainfed cultivation. Late maturity duration (120-125 days). High grain yielding (32.17 q/ha), Moderately resistant to leaf blast, finger blast, neck blast, foot rot and banded blight (PDI). Found superior in respect to protein (6.98%), total mineral matters (4.33%), Fe (3.80 mg/100g), Zn (2.46 mg/100g) and calcium (470 mg/100 g) as compared with checks, showed the good and high nutritional value.
Chhattisgarh Ragi-3 (FMV-1102) (BR-14-3)	S.G College of Agriculture and Research Station, Kumrhawand, Indira Gandhi Krishi Visvavidyalaya, Jagdalpur, Chhattisgarh	Assam, Bihar, Chhattisgarh, Jharkhand, Uttarakhand and Madhya Pradesh.	Suitable for Non lodging and non shattering, responsive to fertilizers, suitable to rainfed and water stress conditions. Tolerant to finger, neck and leaf blast disease, moisture stress and moderate drought spells.Moderately resistant to gross hopper and shoot aphidAverage grain yield: 32.02 q/ha Maturity 110-115 days.
ATL 1 (TNEc 1285)	Centre of Excellence in Millets, Tamil Nadu Agricultural University, Athiyandal, Tiruvannamalai District, Tamil Nadu	Tamil Nadu	Suitable for Rainfed : *Aadi* (June-August) and *Puratasi* (September - October) *pattam*.Irrigated: *Margazhi* (December, January) and *Chittirai Pattam* (April, May). Resistant to: leaf, neck and finger blast. Tolerant to Drought Average grain yield: 30.08 q/haMaturity: 105-110 days.
Dapoli-3 (DPLN-2)	College of Agriculture, Dr. B.S. Konkan Krishi Vidyapeeth, Dapoli, Dist- Ratnagiri, Maharashtra	Maharashtra	Protein content 7.52 per cent calcium content 264 ppm, Iron content 121 ppm (Suitable for Rainfed Upland)
Birsa Marua 3	Birsa Agricultural University, Ranchi, Jharkhand	Jharkhand	ecology /Timely sowing Moderately Resistant to Neck and Finger Blast and resistant to Brown spot, Banded sheath blight and Foot rot. Resistant to major insect/pest *viz.*, Myllocerus weevil , ear head caterpillars, stem borers and grass hoppersTolerant to Moisture stress tolerant during dry spell.Average grain yield q/ha :26.9 q/ha Average : 110-112 days Fodder Yield: 69.7 q/ha Maturity days: 110-112 days.

small millets has received a little more attention than the rest. An attempt has been made here to trace the progress especially in the field of crop improvement during the last 9 decades. In early 1950s and 60s; the crop improvement was confined to fewer states such as Tamil Nadu Andhra Pradesh, Karnataka and Uttar Pradesh. The emphasis was on varietal improvement through selection of better types from local cultivars. In Tamil Nadu, Millet Research Station was established in 1923 at Coimbatore under the erstwhile Madras Presidency. Finger millet work in Karnataka dates back to 1900, initiated at Bangalore especially on finger millet and in Uttar Pradesh at Kanpur and Gorakhpur in 1944. The earliest reports of finger millet improvement are from India, where crop improvement was initiated by Dr. Leslie C. Coleman, the second Director of Agriculture of Mysore in Karnataka state. The first finger millet variety released in the country was H 22 as early as 1918 in Karnataka. The other finger millet varieties released were CO5 (1953); R 0870, ES13, K1, ES11 (1939); Hagari1 (1941), CO1, CO2, CO3, CO4 (1942), VZM 1, VZM 2 (1958) and T36 B (1949). The varieties *viz*., OUAT 2, BM 9-1, BM 11-1, Nilchal and Dibyasinha from Odisha University of Agriculture and Technology and CO series *viz*., CO1, CO2 and CO3 from TNAU, Coimbatore were released following mutation breeding. These varieties were characterized with white coloured grains, dwarf plants, early duration, non lodging, long ears and profuse tillering. Finger millet improvement got a fillip in Karnataka during 1950-60 and several new varieties such as Aruna, Udaya, K1, Purna, ROH 2 and Cauvery were released (Madhusudan *et al*., 2016). So far, a total of 141 varieties of finger millet have been released in the country of which 55 per cent were released following pedigree selection, 39 per cent through pure line selection and only 6 *percent* following mutation breeding. The list of recently released varieties and their adaptation is presented in Table 1.

Molecular markers are one of the important tools employed for the identification and improvements of particular traits. The DNA based markers provide foundation for a wide range of molecular marker techniques which are being widely used in the crop breeding programme (Babu *et al*., 2007). Only limited number of genetic and genomic studies has been undertaken for the improvement of finger millet. The finger millet genome has been sequenced (1.5 Gb) (Hittalmani *et al*. 2017). As reported by Antony *et al*. (2018), finger millet has only 1934 ESTs associated with drought, salinity and disease-tolerance traits. Studies have also revealed high transferability of genic SSR markers associated with tolerance to climatic stresses and superior agronomic traits, such as blast tolerance, Ca, and yield among grasses, including finger millet (Ramakrishnan *et al.* 2017). Such transferability of genomic resources from other well-studied grasses to finger millet, supported by the extensive gene-level synteny shared between the grass genomes, could be useful for improving the less-studied orphan crop for many complex climatic stresses. Using Roche 454 and Illumina Next Generation Sequencing (NGS) technologies, 10,327 SSRs and 23,285 non-homeologous first SNPs were reported in finger millet (Gimode *et al*. 2016). Furthermore, following the recent whole- genome research development for finger millet (Hittalmani *et al.* 2017), ample genomic resources with numerous opportunities for climate smart agriculture has been reported. This wealth of high-quality genomic data that include among others 114,083 SSRs, 1766 R-genes, 2866 drought-responsive genes, 146 C4-pathway genes, 56 families of transcription factors (TFs) and 330 calcium transport and accumulation-related genes also exists at the NCBI Gene bank database for public use. Possibly, it could serve as a reference for modernizing finger millet molecular research in the future.

CONCLUSION

Finger millet is a highly self pollinated crop. The cross pollination by wind or insects is reported to contribute less than 1%. Development of emasculation and hybridization techniques created the opportunity to improve the crop and develop high yielding varieties. Identification of Partial male sterile line (PS 1) plays a key role in the enhanced recombination by combining many favorable alleles and utilization of heterosis. There is a possible hope to challenge the crisis of sustainable food production through development of high yielding varieties in widely adapted nutrient-rich crops like finger millet. Diversified lines of PS 1 also developed; these lines could be used for extensive crossing work in finger millet. Partial male sterile line with virscence acts as a seedling marker this will be useful in F_1 identification at seedling stage itself. These will future facilitates recurrent selection in finger millet. The crop improvement is aimed at developing high yielding varieties with resistance to blast disease, quality fodder, early and medium maturity. So far, a total of 141 varieties of finger millet have been released in the country. The production demands of finger millet have been achieved, even though there was a reduction of half the area in finger millet. This has been mainly due to the increase in productivity from just a mere 704 kg/ha in 1951-55 to 1662 kg/ha during 2019-20. Besides, there is a need to develop new varieties tolerant to drought and high temperatures suitable varied climates and specific situations. Also it is essential to develop bio-fortified varieties for nutrition security.

Conflict of interest: none.

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