Review Article

Floral biology and Breeding System in Kodo millet (*Paspalum scrobiculatum*)

Abstract

Kodo millet belong to group of small millets and family Poaceae. Flower opening in this crop is cleistogamous type, in which explains the complete absence of natural crossing in it. Hence, self pollination highly predominates. The flowers, flowering, panicle arrangement and floral morphology of kodo millet are not clearly understood botanically. The knowledge of floral structure, floral biology, pollination behaviour and breeding techniques are pre-requisite for understanding the system and its manipulation for creating variability, which is largely lacking in small millets. The present investigation deals with the origin, floral morphology, anthesis and pollination, breeding behavior, breeding methods and maintenance breeding of kodo millet.

Keywords: Floral biology; Flowering mechanism; Reproductive biology; Hybridization; Maintenance breeding

Introduction

"Millets are well known as miracle grains and future crops and so of the utmost importance.The climate model predicts that by the end of 21st century, South Asia will be the most adversely affected region by climate change and variability. Delayed monsoon season (up to 15 d) accompanied by less summer precipitation and longer breaks between rainy periods are predicted. Similarly, temperature increase of as much as 3 to 4°C has been also predicted for India" (Ashfaq et al. 2009). "Among the 7000 species, only 20 species cater the 90% requirements for food to the global population" (Collins and Hawtin, 1999). "Interestingly, rice, wheat and maize constitute 60% of the diet and are termed staple crops" (Chivenge, Mabhaudhi, Modi and Mafongoya, 2015; Collins and Hawtin, 1999). "The rest of the crops remain "underutilized" irrespective of their potential to cater to the needs of food and nutrition to the global population. One such underutilized group of crops are the millets.Most of the millets, including barnyard, kodo and little millets, are hardy crops adapted to marginal lands in hot, drought prone arid and semiarid environments" (Dwivedi et al. 2012). "Millets, which are comprised of a number of C_4 small grained, annual cereal grasses have abundant within-species racial diversity. Among the millets kodo millet has a number of important features such as high fertility, more herbage, large number of seeds per ear, branched ear and unique storage ability. The grains are used as food, fodder and also be endowed with antioxidant therapeutic properties" (Chandrasekara and Shahidi 2011). "Grains of kodo millet are extremely resistant to storage pests and can be stored for indefinite periods" (Yenagi et al. 2010). "Its grains are cooked like rice. Kodo millet like other millets is rich in macro and micro nutrient contents. It has higher protein content (8.3/100 g grain) as compared to rice, finger millet, barnyard millet and little millet. Its riboflavin content (0.10 mg/100 g grain) is also higher than rice and barnyard millet. It is also rich in magnesium (166 mg/100 g) and is considered as one of the nutritious millets" (Muthamilarasan et al. 2015). Kodo millet also has considerable production potential in marginal, low fertility soils and chronic moisture deficient areas of the country and plays an important role for the food security of the people inhabiting dry and marginal lands. This makes it as one of the ideal crops in the eon of changing climate and despite of little attention paid to such crops, these serve as prospective sources of unique alleles. FoxtailMillets in general is an under researched crop commodity, and so, no systematic crop improvement programme exists for kodo millet and Little millet.

"Kodo millet (*Paspalum scrobiculatum* L.), is a tropical small millet indigenous to India (De Wet et al. 1983) and grown for its grain and fodder". "It is a traditional, long duration, hardy and drought resistant crop cultivated" (Bondale, 1994). "The area under kodo millet cultivation is witnessing a declining trend in the post- green revolution period due to predominance of the major ce- reals such as rice and wheat. However, an intensified drive to increase the acreage of small millets is important because millets still contribute to the regional food security of the dry and marginal lands, where major cereal crops fail to yield. Nowadays, thrust to grow millets is given due to their nutri- tional superiority as compared to the major cereals. Kodo mil- let has been reported to have higher free radical quenching po- tential when compared to other millets" (Hegde and Chandra, 2005). Besides, "it provides low priced protein, minerals and vitamins in form of sustainable food" (Yadava and Jain, 2006). "Growing health consciousness among the consumers also cre- ates demand for this type of nutri-cereals which are anti- diabetic and anti-oxidant in nature" (Chandrasekara and Shahidi, 2011) . Hence, technological intervention in this crop is essential to boost the production on a profitable scale. Kodo millet is predominantly grown as a pure crop and yields high net returns as compared to other dry land crops owing to its high unit area productivity and market price of the produce in addition to its fodder value. Besides the food crops *viz*., rice, wheat, maize, sorghum and pearl millet, there are other food and feed crops grown in the country. Among the other crops, hill millets figure prominently which include finger millet (ragi, nagli), little millet (vari, kutki), kodo millet (kodra), foxtail millet (kang), proso millet (cheena) and barnyard millet (banti). The kodo millet (*Paspalum scrobiculatum* L.) having chromosome no. 2n=2x=40 is a highly drought resistant crop and coarsest of all food grains. It is a minor grain crop in India and an important crop in the Deccan plateau. It is an important food grain crop in the tribal areas and very popular among the tribal farmers with their food habit and sometimes as a medicinal purpose.

Paspalum scrobiculatum var. scrobiculatum is grown in India as an important crop, while *Paspalum scrobiculatum var. commersonii* is the wild variety indigenous to Africa. The kodo millet, also known as cow grass, rice grass, ditch millet, Native Paspalum, or Indian Crown Grass originates in tropical Africa and it is estimated to have been domesticated in India 3000 years ago. The domestication process is still ongoing. In southern India, it is called kodo or kodra and it is grown as an annual. It is a minor food crop eaten in many Asian countries, primarily in India where in some regions it is extremely important. It grows wild as a perennial in the west of Africa, where it is eaten as a famine food. Often it grows as a weed in rice fields. Many farmers do not mind it, as it can be harvested as an alternative crop if their primary crop fails. In the Southern United States and Hawaii, it is considered to be a noxious weed. In India, kodo millet is ground into flour and used to make pudding. In Africa it is cooked like rice. It is also a good choice for animal fodder for cattle, goats, pigs, sheep and poultry. In Hawaii, var. *scrobiculatum* is found to grow well on hillside slopes where other grasses do not flourish. It has the potential to be grown as a food source on hillside farms. It may also have potential to be used as grass ties on hillside plots to prevent soil erosion, while also providing a famine food as a secondary purpose. It has been noted that it makes a good cover crop. Kodo millet has large potential to provide nourishing food to subsistence farmers in Africa and elsewhere. Understanding of the parameters that affect the duration of the flowering period, pollination behaviour and seed set is prerequisite for increasing the productivity and yield stability as well as improving the efficiency of the breeding program for successful hybridization. The main problem associated with all the small millets is the difficulty in emasculation due to the small size of florets. However, "small millets are raised on lands where no other crop worth mentioning can give a reasonable quantity of nutritionally balanced grain and valuable straw yields. It is good source of protein, very rich in carbohydrate, fat, mineral and vitamins and should be considered as essential food for nutritional security" (Patil et al. 2019). Hence, these crops need attention of scientists, developmental agencies, processors, nutritionists and policy makers in order to not only sustain the production but also to enhance demand so that millet farmers can be benefited. The variety CO 3 released during 1980 and then variety TNAU 86 was released during 2017, CKMV 1 and ATL 1 was released during 2020 and 2021 respectively by Centre of excellence in Millets, Tamil Nadu Agricultural University, Athiyandal.

It is grown predominantly as sole crop or mixed with red gram, sesamum, niger and black gram. The traditional methods of dehusking using earthen mortar with wooden pestle and debraning by hand operated wooden pestle still persists. Debranned grain are white to dull white and resembles rice. Industrial utilization of the grains is still to be explored. Medicinally, kodo millet is used in curing inflammation, diseases of liver, dysentery and considered to keep the body warm. As a coarse cereal, kodo millet has largely remained as the food of less privileged section of the population. Realizing the role of kodo millet, the future thrust should be improvement in yield, adaptability, resistance to biotic and abiotic stresses, fodder and grain quality along with varieties suitable for multiple and inter cropping systems. "They are grown on diverse soils in the area with wide difference for thermo and photoperiod. These unique qualities have made them as choice crop to rainfed, tribal and hill agriculture where options of crops are limited. Besides this now a day awareness regarding nutrition is increased which also increased the demand of hill millets. The productivity of other hill millets except finger millet, is low due to poor soil fertility and age-old cultivation methods. Small millets area in the country has come down substantially in the last two decades and is likely to go down further in coming years; particularly in other small millets except finger millet" (Gautam and Kaushik, 1981).

Origin, domestication and taxonomy

"Kodo millet *(Paspalum scrobiculatum* L.; Plicatula group; family : Poaceae; Sub family : Panicoideae; Tribe: Paniceae) is one such important millet and are tetraploids (2n = 4x = 40; genome size 1.91–1.98 pg)" (Burton 1940; Jarret et al. 1995). "Kodo millet is indigenous to Indian sub continent. It was domesticated in India around 3,000 years ago, and India has historically been the major center of cultivation" (de Wet et al. 1982). The cultivation of kodo millet as food crop appears to be confined to India only although it is grown in China, Japan and Australia. The species is widely distributed in damp habitats across the tropics and sub tropics and seen throughout Indian sub continent. It is an annual grain that is grown in primarily in India, but also in the Philippines, Indonesia, Vietnam, Thailand and in West Africa where it has originated. It is grown as a minor crop in most of these areas, with the exception of the Deccan plateau in India where it is grown as a major food source.

"Kodo millet accessions have been classified into three races based on panicle morphology: regularis, irregularis, and variabilis" (de Wet et al. 1983).

Area of Cultivation

India and West Africa are the major growers of kodo millet (*Paspalum scorobiculatum* L.). With an area of about 9.0 lakh hectares and annual production of about 3.11 lakh tonnes, Kodo millet ranks first among small millets excluding finger millet and contributes 36.61 per cent and 31.32 per cent to total area and production of small millets in the country. The national yield level of the crop is 342 kg/ha. As a coarse cereal, kodo millet has largely remained as the food of less privileged section of the population.

In India, the crop is cultivated in an area of 224 thousand hectares with annual production of 73 thousand tones. The productivity of kodo millet is 312 kg/ha (Anon, 2017). Madhya Pradesh rank first in area of kodo millet, which shares about 60% of its total area of country. Other major states growing kodra are Maharashtra, Tamil Nadu, Chhattisgarh, Andhra Pradesh, Karnataka and Gujarat. In India, Kodo millet occupies an area of 9.08 lakh ha with an annual production of 3.11 lakh tones and average productivity of 342 kg/ha. Among the small millets, productivity per unit area is highest in kodo millet (Anon. 2018)

In India it is mainly cultivated from Tamil Nadu and Kerala (in Southern India) to Uttar Pradesh, Rajasthan and West Bengal (in Northern India). But in Africa it is either cultivated or harvested in wild.A wild form of the species is frequently seen in water logged lands, low lying areas and on the bunds in rice fields. The crop is known in different names *viz.,* kodo (in Hindi), arugu (in Telugu) and varugu (in Tamil) in India and as bird's grass or black rice (Porteres 1976) in Africa.

Among small millets in India, kodo millet ranks second in area after ragi. Two states, Mathya Pradesh and Chattisgarh account for more than 6 lakh hectares and 75 per cent of the total area in the country. The grain after dehusking is cooked in the form of rice. In southern India, there are small (*kuru varagu*) and large seeded (*peru varagu*) varieties recognized, often grown together in the same field. General morphological variability is high, with large variance reported in many phenotypic parameters such as time before flowering, tiller number, and yield (Subramanian et al. 2010; Upadhyaya et al. 2014).

Kodo millet is grown generally in rainy season as dryland crop in Tamil Nadu and occupies an area of 1861 ha with a production of 1572 tonnes and productivity of 844 kg/ha. The crop grows well in shallow as well as drained soils in districts like Cuddalore, Villupuram, Ariyalur, Madurai and Perambalur.

Botanical Description

In spite of its long history of cultivation, the variability seen in cultivated land races is very much limited. It is an annual with stems 60-90 cm long and showing profuse tillering. Spikes are 2-6 in number and 3-15 cm long. Spikelets are normally sessile or with short pedicillate arranged on a flattened rachis. The arrangement of spikelets is in two or more regular or irregular rows. The most common kodomillet is characterized by racemes with the spikelets arranged in two rows on one side of a flattened rachisis called as regularis type (Fig. a and b). Plats with irregularly arranged spikelets called as irregularis (Fig. c). Two kinds of aberrations occurs. In one kind, the spikelets are arranged along the rachis in 2-4 irregular rows (Fig. 1). In the other aberrant kind, the lower part of each raceme is characterized by irregularly arranged spikelets, while spikelet arrangement becomes more regularly two rowed in the upper part of the raceme (Fig. 1).The spikelets are flat, broadly elliptic, awnless with two florets of which the lower is reduced and rudimentary. Flowers are highly cleistogamous and self pollination is the rule. The grain is enclosed in hard persistent husk, which is removed after dehusking (Subramanian et al. 2010). Raceme morphology allows for the recognition of three complexes.

a) Erect **b) Decumbent** **c) Prostrate**

Fig. 1 Different growth habits of kodo millet

Climate resilience crop

In the recent past, the cultivation of kodo millet was widely extended to different agro climatic situations. It is known for its hardiness and can withstand moisture stress as well as waterlogged situations. The grain has very good storability and free from store pests. There are observations that the grain becomes poisonous if caught in the rain. The consumption of such grain is known to produce unconsciousness or violent tremors of temporary nature. However, the exact reason for the poisonous effect of the grain is not clearly understood and it is suggested that the glumes, lemma and palea might contain poisonous alkaloids.

Special Features

It is a very hardy crop, drought tolerant and can survive on marginal soils where other crops may not survive, and can supply 450–900 kg of grain per hectare. However, kodo millet has the potential to yield around 3500-4000 kg/ha under favourable environment.

It is drought tolerant and can be grown in a variety of poor soil types from gravelly to clay (de Wet et al. 1983b; MRibu and Hilu, 1996). Most genotypes take 4 months to mature (de Wet et al. 1983b). Like foxtail millet, a weedy counterpart of kodo exists and is problematic throughout the old world farming systems especially in damp areas (de Wet et al. 1983b; Becker and Johnson, 2001). It is believed that kodo was probably first harvested as a weed alongside other cereals like rice, perhaps leading to multiple domestication events of the millet across its current range (de Wet et al. 1983b). Kodo millet is divided into three races (*regularis, irregularis,* and *variabilis)* based on panicle morphology. *Paspalum* *scrobiculatum* var. *scrobiculatum* is grown in India as an important crop, while *Paspalum scrobiculatum* var. *commersonii* is the wild variety indigenous to Africa.

Nutritional profile of Kodo millet

Its grains are cooked like rice. Kodo millet like other millets is rich in macro and micro nutrient contents. It has higher protein content (8.3/100 g grain) as compared to rice, finger millet, barnyard millet and little millet. Its riboflavin content (0.10 mg/100 g grain) is also higher than rice and barnyard millet. It is also rich in magnesium (166 mg/100 g) and is considered as one of the nutritious millets (Muthamilarasan et al. 2015). Kodo millet also has considerable production potential in marginal, low fertility soils and chronic moisture deficient areas of the country and plays an important role for the food security of the people inhabiting dry and marginal lands. This makes it as one of the ideal crops in the eon of changing climate and despite of little attention paid to such crops, these serve as prospective sources of unique alleles. Kodo millet among all millets has the highest free radical quenching potential, thus possessing good antioxidant property (Taylor and Emmambux, 2008). However, kodua poisoining was reported when kodo millet grains infected with *Aspergillus flavus* or *A. tamarii* were used as food or feed. Both fungi produce cyclopiazonic acid, which causes kodua poisoning (Rao and Husain, 1985), which results in sleepiness, tremors, and giddiness in humans (Bhide, 1962).

Table 1. Nutritional status of Small millets

Millet	**Iron (in mg)**	**Calcium (in mg)**	**Minerals (in g)**	**Fibre (in g)**	**Protein (in g)**
Pearl millet	16.9	38	2.3	2.3	10.6
Finger millet	3.9	344	2.7	2.7	7.3
Foxtail millet	2.8	31	3.3	3.3	12.3
Proso millet	0.8	14	1.9	1.9	12.5
Little millet	0.5	27	2.6	2.6	8.3
Kodo millet	**9.3**	**17**	**1.5**	**1.5**	**7.7**
Barnyard millet	15.2	11	4.4	4.4	11.2

Flowering mechanism of kodo millet

I. Panicle Emergence:

The panicle arises usually from the node. The first sign of the growing panicle is a slight bulge of leaf sheaths. The swelling increases gradually and the panicle is seen through the sheath slit. It takes about a week for it to emerge. When fully, emerged it is enclosed by three overlapping leaf sheaths which in roll one inside another at the top. The flag and the leaf below it, likewise in roll at the top and, in most cases, do not separate even when the panicle is in full flower. In the in rolled region mentioned above the ends of the inflorescence remain stuck up. The upper end thus fixed, the floral branches, as they elongate, bend outwards at the centre. The enclosing leaf-sheaths are forced apart by the rapid growth and consequent arching of the panicle until thereby the tips are also forced out. This is the general rule but in variety imported from Sierra Leone, the peduncles clear out of the leaf-sheaths, elongate and hold the panicles aloft and away from the leaf-sheaths.

Fig. 2 Complete Panicle Emergence

II. Panicle Arrangement:

Excepting the lower three nodes, the other two bear panicles. From each of the two upper nodes three separate peduncles arise. Of· these, the central one aborts and the two lateral grow. The abortive one bears a sessile panicle. This panicle may contain one or two branches bearing rudimentary spikelets. Of the two free growing peduncles, one grows quickly and shows out earlier than the other. The earlier is always bigger and has more spikelets less of sterility. In the later peduncle the spikelets at the tips of the branches are usually sterile. Each of these peduncles gives rise to three branches one of which aborts, the other two showing a likewise differential growth and development. These branches repeat this timorous process until small spikelet-bearing branches of differential size arise and produce flowers. In this ultimate trimerousness some of the abortives get converted into long stalked single flowers. The weaker flower-bearing branches are mostly unbranched, whereas the stronger ones branch out and bear a larger number of flowers. The largest number of spikelets in a branch may be as many as 100.

Fig. 3 Panicle Arrangement

III. Panicle Branches:

Each branch has a broad, flat rachis with a series of depressions corresponding to the situation of the spikelets. On the side on which the spikelets are situated, a central ridge runs along the entire length. On either side of the ridge the spikelets are arranged alternately in two series on short pedicels. In some varieties instead of the usual two-seriate condition, a branching of the pedicel gives rise to a non-seriateness, the spikelets being irregularly arranged. At the base of the branch it is two-seriate; in the middle the non seriate condition prevails; and towards the tip the two· seriateness continues. The nonseriate condition is found in some cases along the entire length of the branch, other variants to the simple branching of the pedicel and the production of two flowers are the following:

(1) The pedicel instead of forking into two, branches into three, each bearing a spikelet.

(2) It may bear more than four flowers at different levels.

(3) Small branches arise at different levels on the ridge of the branch and these bear a fairly large number of flowers.

Fig. 4 Different View of Panicle Branches

In addition to the crowding; induced by the branching of the pedicel, the double seededness of such non-seriate heads is the most important factor in the crowding and small size of the grain in the earheads that are not two-seriate. The disturbance of two-seriateness brings about a dense packing of spikelets on the flat rachis and contributes to the reduction in the size of the spikelets. Consequently the spikelets in these are 1/3 to 1/2 the size of those in the two-seriate panicles. It may be observed that the non-seriate varieties are early, lighter pigmented with grains of a lighter brown husk.

IV. Spikelet-Single Seeded:

The description of this spikelet has been elaborated from Hooker's Flora of British India in which a description of the variety with double seeded spikelets is not found. Spikelets orbicular, mostly decidedly plano-convex, falling entire from the short rudimentary pedicels and abaxial on the dilated rachis of spike-like racemes.

Fig. 5 View of Regular, Irregular and Varigatum Types of Panicle

Glume 1	:	0 (suppressed.)
Glume II	:	More or less equal to the spikelet; convex; membranous; light green: deciduous; glabrous; 5-6 nerved.
Glume III	:	Similar to Glume II. but less convex and more flat; light green; thin; glabrous :deciduous; 2-5 nerved; along the inner margins are seen shallow transverse pits, hence the specific name “scrobiculatum”.
Glume IV	:	Horny; pale green; later develops a light or dark brown colour; glabrous; 5 transparent nerves; margin firm; obtuse; emucronate; persistent.

Palea : Tightly embraced by the narrowly involute margins of Glume IV; similar in substance to Glume IV ; 2 transparent nerves the palea with flaps widened into a broad auricle below the middle: persistent.

Stamens : Three; filaments short, 1 m. m. long. anthers-3, 2-3 mm. long; 2-loculed; locules open by longitudinal lateral sutures .

Ovary : Ova1; translucent; stigmas·-2. styles distinct and laterally exserted near the tip of the floret; styles feathery from one-third the length from the apex

Lodicules : Two; fleshy; serrated tips; broadly cuneate.

Grain : Tightly enclosed by the slightly hardened glume and palea; rotundate-elliptic; very convex in front. flat on the back; pale; scutellum up to half the length of the grain.

Spikelet : Double Seeded. In the double-seeded spikelet, between Glume II and palea of Glume IV an extra flower is interpolated. It is enclosed in an extra glume and palea. This extra flower develops seed, each spikelet thus having two seeds. Abortive conditions of this double seededness freely occur interspersed with this double fertility and arise as follows. An extra flower is developed between Glume II and palea of Glume IV. It is a perfect flower and has only an extra palea. It does not set seed.

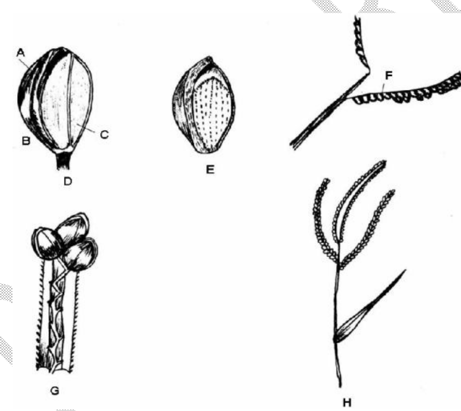

Fig. 6 Floral parts of Kodo millet

(A) Upper floret; (B) Second glume; (C) Lemma of lower floret; (D) Spikelet; (E) Floret; (F) Rachis; (G) Arrangement of rachis in spikelet; (H) Inflorescence.

Opening of the Flower:

The opening of the first flower is generally on the second day after the emergence of the panicle. This flowering begins between 2.30 and 3.00 a.m. on each day and continues till sunrise. Youngman and Roy (1923) note that these flowers open between 7.30 and 8.00 a. m. at Nagpur. Flowers do not commence to open from any definite region. They usually start from the middle of the floral branch and gradually spread to either ends. Instances in which flowers begin to open at either end are met with occasionally.

Anthesis of a Flower (anthers extruded):

Detailed observations on the anthesis in a normal average flower are recorded below showing the trend of sequence.

2.30 a.m - Glumes begin to open.

2.40 a.m - Anthers visible through opening.

3.15 a.m - Anthers emerge.

3.30 a.m - Anthers completely out.

3.35 a.m - Anthers dehisce.

3.45 a.m - Glumes close completely.

The stigmas may or may not come out of the glumes. When the glumes begin to gape, the anthers crowd at the orifice and are un-dehisced. They are mostly non-emergent. Their filaments are 1 mm. in length. In stray cases anthers emerge, their filaments being 6 mm. long. These filaments remain turgid for a long time, often till 8-9 a.m. The anthers may emerge simultaneously or one by one or two at a time followed by the third. This stray emergence accounts for the paucity of evidences of flowering in this unobtrusive millet. When the anthers remain inside the flower, their dehiscence takes place long after the opening of the glumes. Dehiscence starts as a slit at one end and gradually spreads or' it begins in the middle and proceeds to the ends. The stigmatic feathers dry in the evening. The anthers remain fresh and do not wither till next morning. The lodicules are fleshy and do not shrink immediately after the anthesis of flowers but remain fleshy for 6-8 hours after the opening of the glumes and then dry up a probable device preventing the closing glumes from jamming the anthers (Ayyangar and Rao, 1934)..

Progress of Flowering:

The following table connotes the daily anthesis energy of the 15 per cent of flowers opening during the flowering period, emerging and non-emerging anthers included.

Chart 1 : Daily anthesis energy

Days of Flowering	**2-3 a.m**	**3-4 a.m**	**4-5 a.m**	**5-6 a.m**	**Total**
First day	14	1	1	-	16
Second day	2	10	-	1	13
Third day	7	11	-	-	18
Total	23	22	1	1	47

*** 15 per cent of the flowers in the head opened. The remaining 85 per cent were cleistogamous**

It will be seen that all the flowers in the head do not open. The percentage of open flowers in the varieties varies from nil to 50 per cent., the most frequent being 10 to 15 per cent. This millet is therefore highly cleistogamous which explains the complete absence of natural crossing in it. Any artificial manipulation of the spikelet irretrievably damages it and many attempts at emasculation and artificial pollination proved futile.

Grain

The grain matures in 30-35 days after flowering: It is tightly enclosed by the hardened fourth glume and its palea. The husk is coloured shades of brown. In the two seriate varieties, the grain is bigger and nearly twice the size of those in the non-seriate ones. In the variety imported from Siena Leone (referred to above), though the head is two-seriate, the grain is small. The degree of emergence of the heads has no effect on the setting of the seed, both having about the same degree of sterility. In this millet seed-setting is dependent on the season. In the year 1928, the drought affected the seed-setting in some varieties to such an extent that not even a few, grains per plant could he obtained. Under favourable conditions good yields can be expected.

Fig. 7 Brown colour husk of grain

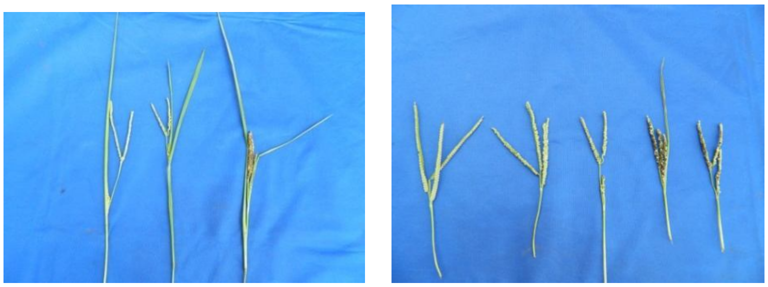

Fig. 8 Variation in Panicle Morphology

Floral morphology

Kodo millet inflorescence comprises of 2-6 racemes spread- ing widely on a sub-digitate or a short axis (Fig. 7). The racemes are 3-15 cm long (Seetharam et al. 2013). The spikelets are usually sessile or on a short pedicel. They are usually single arranged in two rows on a flattened rachis (Ramakrishna et al. 2002). In the middle of the raceme, some spikelets are paired. The rachis is ribbon like, 1.5-3 mm wide having scabrous margins. The spikelets are arranged alternatively in two series i.e. long and short pedicelled (Nanda and Agrawal 2008). The glume I is absent and the glume II is equal to the length of spikelet. The lemma I is almost similar to glume II while lemma II encloses both the two florets. The lower floret in the spikelet is sterile and reduced to valve, whilethe upper one is a hermaphrodite flower (Sundararaj and Thulasidas 1976). The grain is enclosed in hard horny persistent husks (Seetharam et al. 2003).

Anthesis and pollination

Kodo millet has a cleistogamous flower (Yadava 1997) and the percentage of open flowers does not exceed 15-20% thereby self-pollination is the rule. Spikelets located on the middle of the raceme opens first and gradually spread to both ends (Sundararaj and Thulasidas 1976). Spikelet opens between 2.30 a.m. to early morning (Jayaraman et al. 1997). The lemma is very tight and any attempt to open the florets through artificial manipulation damages the flower. Protogyny has been observed in some cultures of Kodo millet like IPS 147, IPS 197, IPS 427 (Harinarayana 1989). Some species of genus *Paspalum* are known to be apomictic (Casa *et al.* 2002). However this trait has not reported in Kodo millet.

False Polyembryony

In the year 1931, in the course of a number of seed germinations for albinism in this. millet, two instances of two seedlings arising from a single seed were noticed. The seedling had a single root and two plumules each with its own coleoptile. At the surface of the seed, the two were separate. Paraffin sections of the seed showed that the plumules had independent vascular bundles. Lower down, the cortical portions of the two shoots were found to unite, the bundles running separate. In a few sections lower down, the vascular bundles were closer and approached each other until finally they became enclosed in a single endodermis. Sections still lower down showed the root strand run into this single bundle. From this examination of the course of the vascular bundles and also of the cortical region, it will be seen that what appears to be independent at the top is, in reality, the result or the branching of a single seedling.

At a very early stage in the development, the mesocotyl has branched into two, resulting in the double seedling a case of false poly embryony. Cases of pseudo-poly embryony have been recorded by other workers. Only those pertaining to the Gramineae are noticed. In maize, Kiesselbach (1926) noted seedlings with (1) two plumules each with its own coleoptile and two primary roots enclosed in a single coleorhiza, (2) a single plumule with two primary roots in a single coleorhiza. In the case reported here, there are two plumules each with its own coleoptile but with a single radicle.

Conventional breeding approaches

Conventional breeding approaches have been successful in characterizing small millets germplasm and their use in developing and releasing several cultivars, including for resistance/tolerance to biotic and abiotic stresses. Various breeding methods such as pure line selection, pedigree selection, mass selection, and mutation breeding, which are applicable to self-pollinating crops are followed in small millets as well. Reports on small millets cultivars released over a period of time shown that a majority of them were released following selection from local landraces/cultivars, For example, in India, of the 248 varieties of six small millets kodo millet 33, barnyard millet 18 and little millet 20), about 65% were released following selection from landraces, about 30% through pedigree selection, and 5% through mutation breeding.

Mutation breeding

In general, mutation breeding has played a key role in to create variability. Mutation breeding has resulted in the release of 13 small millet cultivars (finger millet 8, kodo millet 3, and little millet 2) in India. The use of chemical hybridizing agents (CHAs) to induce male sterility in small millets needs to be explored. The usefulness of mutagen depends on its mutagenic effectiveness (mutations per unit dose of mutagen) and efficiency (mutation in relation to undesirable changes/damage like sterility, lethality, injury etc.) in order to recover a high frequency and spectrum of desirable mutations.

As genetic variability is essential for any crop improvement programme, the creation and management of genetic variability become central base to crop breeding in any crop and more so in crops like kodo millet, in which the available genetic variability is very limited owing to complete self-pollination in this crop due to its cleistogamous nature (Harinarayana,1989). Among the approaches, to create genetic variability, induced mutation is an important approach. Mutation is gene level alterations in the structure and position of DNA base pairs on chromosome called point mutation. Changes within the DNA molecule are referred to as “point mutations” since they occur in a small portion of the DNA but may still have significant effect because they change the “meaning of the code.”This results in the alteration of phenotype of an organism. Mutation breeding is the tool in the hands of breeders to create variability in crop population and to make selection in the population to bring about further improvement in that crop.

In general mutation breeding plays a key role in self-pollinated crops with limited variability. Gamma irradiation as mutagen can induce useful as well as harmful mutations in plants (Micke and Domini, 1993). Keeping in view the limited genetic variability available in the germplasm, this study aims to induce mutations using different doses of gamma rays and isolate useful plant habit mutations which will be utilized for genetic improvement of kodo millet.

Wide hybridization:

***Paspalum sanguinale*, Lamk.**

Several species of *Paspalum*, especially *P. dilatatum* are grown in America, Australia and South Africa as pasture grass. A wild ally of *Paspalum* known as Chicco (*P. sanguinale*, Lamk) is grown in the Vizagapatinam District. This was grown at the Millets Breeding Station , TNAU, Coimbatore for a number of years. The seed which is very small takes 7 days to germinate, two days later than for Varagu. Unlike *P. scrobiculatum*, the seedlings are green and have no purple pigment anywhere in the plant. Before flowering the plants are spreading and almost prostrate. The panicle bearing tillers become erect at flowering. Unlike varagu the internodes are hollow and much exposed. At ripening stage they have a golden yellow colour. The nodes are glabrous and not swollen. The flag is the broadest leaf in the plant. The upper surface of leaves is rough and the lower is smooth. The leaves are arched and not bent. The plants have five to six heads with long well emerged straight peduncles. Occasionally their fullness leads to goose necking. The panicle has a general resemblance to that of a well grown *Chloris barbata*. It consists of a number of fingers (or branches) arranged in irregular whorls along a short axis. An average earhead may have about 40 fingers. The bulk of these arise from the two bottom whorls, the rest of them being distributed to those above, mostly in twos and threes. Each finger may have about 100 flowers. The spikelets are very small, the length in each being four to five times the width. The glumes are prominently ribbed and dry to a straw colour. The structure of the spikelet is like any other *Paspalum*. The flowers of this wild ally open from 1.00 to 3.00 a.m and the anthesis continues up to 7.00 a.m. The greatest anthesis energy is within the first hour after opening. It takes four to five days for a panicle to complete its flowering.

Conclusion

The Study deals with the origin, floral morphology, anthesis and pollination, breeding behavior, breeding methods and maintenance breeding of kodo millet. The wild *Paspalum* scores over *P. scrobiculatum* in a number of points, *viz.*, more herbage, free earheads, greater drought resistance, larger number of seeds per head and absence of sterility. A cross with this wild ally is indicated as a potential source of improving the kodo millet, if the difficulties in the manipulation of this close and delicate cleistogamous flower could be overcome.

Table 2. List of high yielding varieties in Kodo millet released by TNAU

Variety	Common Name	Year of release	Duration in days	Yield kg/ha	Special attributes
CO 1	-	1953	800	145-150	Non lodging, drought tolerant
CO 2	-	1970	1000	135	Non lodging, drought tolerant
K 1	PLS form local	1979	1800	100	Non lodging, drought tolerant
CO 3	Gengia selection	1980	3000	120	Non lodging, drought tolerant

APK 1	Selection from Panivaragu culture PSC 5	1991	2400 (R)	100	Short duration, non lodging and non shattering suitable for early and late sown seasons withstand short periods of drought, tolerant to downy mildew, smut, ergot and stem borer
Paiyur 1	-	1994	700	125-130	Non lodging, drought tolerant
Vamban1	PLS from "Pall"	1995	1683	95-100	Highly resistant to sheath blight and head smut diseases, tolerant to shootfly incidence
TNAU86	Pure line selection from IPs 85	2017	2709	104	• High milling recovery • Profuse tillering • Non lodging • Tolerant to head smut, sheath blight and brown spot
ATL 1	Pure line selection from DPS 63	2021	2506	105-110	• Drought tolerant • Tolerant to shoot fly incidence • Tolerant to Grain smut and sheath blight • Non lodging and uniform maturity • Sturdy culm • Suitable for mechanical harvesting
CKMV1 (ATL 2)	Pure line selection from DPS63/58	2021	2813	105-110	• High yielding • Short duration • Drought tolerant • Profusely tillering • Non – lodging • Suitable for dry land cultivation

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