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Floral Biology and Pollination System in Small Millets

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ABSTRACT

The flowers and flowering of small millets are poorly understood taxonomically. The knowledge of floral structure, floral biology and pollination behaviour are pre-requisite for understanding the system and its manipulation for developing a proper crossing technique, which is largely lacking in small millets. The present manuscript deals with floral morphology of small millets in particular in the light of the *Poaceae* family.

Keywords: Barnyard millet (*Echinochloa frumentacea*), Finger millet (*Eleusine coracana*), Foxtail millet (*Setaria italica*), Little millet (*Panicum sumatrense*), Proso millet (*Panicum miliaceum*), Kodo millet (*Paspalum scrobiculatum*)

CONTENTS

INTRODUCTION

The grass family *Poaceae* is the fifth largest family in the plant kingdom after the *Orchidaceae*, *Rosaceae*, *Asteraceae* and *Fabaceae*, comprising of over 10,000 grass species classified into 600-700 genera (Watson and Dallwitz 1999; Kellogg 2006) and exhibits a wide range of floral adaptation. Majority of the species under this family are cleistogamous (non-opening) in nature in which pollination take place prior to opening of flowers. Chasmogamy is also been reported in some of the species of *Danthonia* (Philipson 1986) and *Eragrostis*. Corn and pearl millet are naturally cross-pollinated crops and wind is the chief agent of pollination. Corn has protoandry, whereas pearl millet has protogyny. Some of the species of *Poa* (Fritz *et al.* 2005), *Paspalum* (Snyder 1957) are known to be apomictic. Thus, grasses have attracted considerable attention in biological and agricultural sciences because of their economic and ecological importance (Hilu 2007).

A total of 35 species belonging to 20 genera of the family *Poaceae* are domesticated (De Wet *et al.* 1989) and family has contributed crop species that provide 80% of the annual global food (FAOstat 2009). In fact, top crops viz., wheat, rice, corn, barley, sorghum, oat, rye and pearl millet that feed the world are cereals and belong to the grass family. Apart from this, *Poaceae* family contains number of small seeded species known as millet. Millet is a general term for a wide range of small seeded cereals (Marcon 1994) that may be used for grain and/or forage (Schery 1972). In India, commonly grown millets include sorghum, pearl millet, finger millet, foxtail millet, little millet, barnyard millet, proso millet and kodo millet. Sorghum and pearl millet are considered as coarse millet, while the other 6 crops comprised of small millet group (Gupta 2006). Barring the finger millet, productivity of other small millets is less than 1000 kg/ha (Gupta *et al.* 2010). The situation is

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Invited Mini-Review

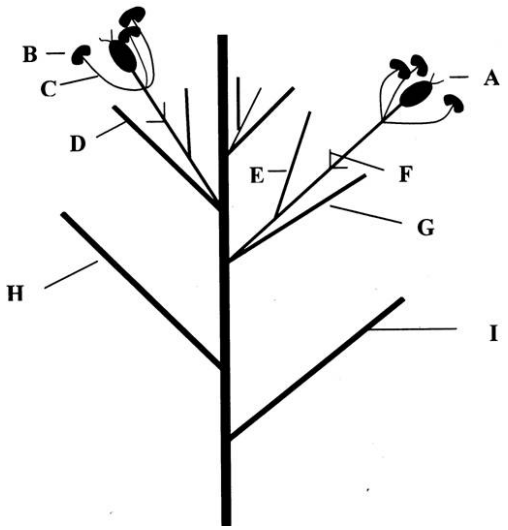

Fig. 1 Floral structure of family Poaceae. (**A**) Feathery stigma; (**B**) Anther; (**C**) Stamen; (**D**) Lemma; (**E**) Palea; (**F**) Lodicules; (**G**) Lemma; (**H**) Lower empty glume; (**I**) Upper empty glume.

quite dismal in kodo and little millet (Seetharam 1998). In general, the productivity of small millets is lower than the major cereal crops.

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. The main aspects related to floral structure and pollination in small millets are summarized here.

FLORAL MORPHOLOGY OF GRASSES

The grasses are characterized by vertical cylindrical hollow stem and strengthened at intervals by transverse septa known as nodes. The leaf blades are borne on sheath arising alternately at the nodes and arranged at distichous series i.e. the odd-numbered sheaths are directly one above another. The inflorescence of the grass family is produced on shoots, which may be terminal and axillary or very often only terminal. Grasses have a complex inflorescence. The terminology applied to inflorescences in the grasses traditionally equates a spikelet with a flower. The inflorescence consists of one or more spikelets each arranged at distichous series of scales in the axils in which flowers are located (Bor 1960). The type of inflorescence may be a spikes, racemes, spike-like racemes or panicles (true and false) type. The inflorescence of grass family has been much used in the study of the grasses as a source of diagnostic character for the identification and its phylogenetic value (Vegetti and Anton 2000).

In grasses, the spikelet is the unit of the inflorescence (**Fig. 1**). The spikelet is defined by the presence of two small bract leaves called glumes and their enclosed floret (Schmidt and Ambrose 1998). The flowers are inconspicuous, are arranged in spikelets and enclosed in chaffey (papery) scales (Bor 1960) known as a lemma and a palea. The whole structure including the lemma, the palea and the flower (carpels, stamens and lodicules) is referred as a floret (Kyozuka *et al.* 2000). Each spikelet may contain one to forty or more florets (Nanda and Agrawal 2008). The fruit is one seeded and ovary wall is united with the seed coat and is called as caryopsis.

The floret consists of gynoecium, androecium and lodicules. The gynoecium consists of the pistil and its contents namely ovary, ovule, style and stigma. The ovary is considered to be formed by three carpels fused together into a hollow ovary in which a solitary ovule attached at the adaxial inner surface of it. It is not clear whether two missing carpels have been entirely suppressed to the extent that only one carpel primordium is initiated or whether they are entirely fused with entirely single fertile carpel (Rudall *et al.* 2005). The ovule is attached to the ovary wall with or without a minute funiculus. At the top of the ovary a hairy fleshy appendage is found. Majority of cereals and millets have two styles except maize which has only one style (Mangelsdorf 1974). The styles end in a stigma, which may be papillose (viscid) or plumose (hairy) in nature. Majority of species of grass family have three stamens except rice (six stamens) (Kellogg 2001). The lodicules are important organs creating the mating system in grasses, in a range between autogamy in cleistogamous and allogamy in chasmogamous species (Kosina 2010). Among the majority of grasses the lodicules are two or three in numbers, when three in numbers, two are found at the margins of the palea, whereas third is on the abaxial surface of the palea. The entire organ complex – lemma, palea, lodicules, stamens and gynoecium – is thus called a floret and relates to the flower in other plants (Kellogg 2006).

FINGER MILLET (*Eleusine coracana* (L.) Gaertn)

Finger millet has been predominantly grown in Southern Asia and Eastern Africa, both for grain and forage (Gupta *et al.* 2010). It is the most important small millet in the tropics (12% of global millet area) and is cultivated in more than 25 countries in Africa (eastern and southern) and Asia (from Near East to Far East), predominantly (ICRISAT 2011a). Its cultivation extends from sea level to higher elevations in the Himalayas (Seetharam 1998). Finger millet is a good source of calcium (358 mg/100 g) and dietary fibre and consumed both in native and processed form (Gopalan *et al.* 1989; Rao and Muralikrishna 2001). Several health benefits such as hypo-cholesterolemic, hypoglycemic and anti-ulcerative are associated with regular intake of finger millet (Shobana and Malleshi 2007). Finger millet grains can be stored for years without being infested by storage pest, which makes it a prefect food grain commodity for famine prone areas (National Research Council USA 1996). The crop is valued for assured crop harvest in low input agro-ecosystem.

Floral morphology

Finger millet inflorescence is in the whorl of 2-11 digitate, straight or slightly curved spikes. The spike is 8-15 cm long and 1.3 cm broad. In each spike, about 50-70 spikelets are arranged alternatively on one side of the rachis (Gupta *et al.* 2010). Each spikelet contains 3-13 florets (Sundararaj and Thulasidas 1976). The florets are covered by two large barren leaves each being enclosed between a pair of scale known as palea (**Fig. 2**). The florets are in the axil of the lower flowering glumes known as lemma, which has small appendage. Near the base of the ovary, two little scaly lodicules are present (Dodake and Dhonukshe 1998). The three stamens having anther 0.5-0.8 mm long, not penicillate (Nanda and Agrawal 2008). The gynoecium is bi-carpellary, uni-locular with superior ovary having two styles with plumose stigma (Seetharam *et al.* 2003). The androecium almost surrounds the stigma, which ensured self pollination. The filament is very short (0.48-0.85 mm), while anthers are bigger than filaments. The feathery branched stigma is of 0.83 mm in length (Dodake and Dhonukshe 1998). The seed is small (1.2-1.8 mm in diameter) and light brown to brick red in colour (Saha *et al.* 2011). However, white grained finger millet genotypes are also developed by various research institutes in India.

Anthesis and pollination

Dodake and Dhonukshe (1998) studied the pollination system in finger millet. Their study revealed that when stigma comes out of the lemma, it is covered with a thick cloud of

pollen dust due to association of elongation of style and filaments with anthers bursting. This condition hardly allows any chance for cross pollination. The anthers get dehisced while still being inside the palea. Soon after the dehiscence of anthers, the flower is observed to be closed with no traces of stigma. Only empty dehisced anthers are observed hanging out from the closed flowers at low humidity and high temperature. At high humidity and low temperature both anthers and stigma are observed hanging outside from the closed flowers. This behavioural sequence predisposes finger millet into cleistogamous as well as chasmogamous species.

Within a spike, spikelet opens from the top to downward while within a spikelet floret opens from bottom to top and one floret in a spikelet opens per day (TNAU 2011). The maximum number of flowers opens on the third day after initiation of flowering. It takes 5-7 days to complete flowering. The anthesis occurs between 1.00 to 5.00 a.m. (Gowda 1997). As soon as lemma and palea begins to gap, the stigma and anthers emerge almost concurrently. The anthers dehiscence longitudinally and it occurs prior to the opening of the florets (Seetharam *et al.* 2003). The sticky stigma and anthers attained the same height inside the flower at the time of dehiscence. The anthers dehisce and pollinate their own stigmas. The pollen remains viable for 20 min while receptivity of stigma is up to 5 h (Dodake and Dhonukshe 1998). Estimation of natural crossing does not exceed 1% in finger millet (Seetharam 1998). 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 treatment of inflorescence (3^{rd} to 4^{th} day of emergence) at 52°C for 5 min (Raj *et al.* 1964) is also found effective in inducing male sterility in finger millet. However, genetic male sterility has also been reported in finger millet. This source of male sterlity carries the ms_1 allele and developed through chemical mutagen treatment (1.5% aqueous solution of ethyl methane sulfonate for 6 h at 25°C) and this genetic male-sterile line was named 'INFM 95001' (Gupta *et al.* 1997).

FOXTAIL MILLET (*Setaria italica* (L.) Beauv.)

Foxtail millet ranks second in the among the millet produced globally world's total production of millets. The annual production of foxtail millet was estimated to be five million tons (Lin 2005) with China being the main producer (3.7 million tons). It is mainly grown on poor or marginal soils in southern Europe and in temperate, subtropical, and tropical Asia (Marathee 1993). It can grow over a wide range of altitudes ranging from sea level to 2000 m above mean sea level. Foxtail millet is fairly tolerant to drought; it can escape some droughts because of early maturity. Due to its short life cycle, it can be grown as a short-term catch crop (ICRISAT 2011b). It is also cultivated as a dry land crop under marginal and sub-marginal lands (Rao *et al.* 1997). It requires water in the later stages of the crop growth but cannot tolerate water logging (Jijau 1989).

Floral morphology

The inflorescence of foxtail millet has a main stalk with shortened side branches bearings spikes and bristles (Baltensperger 1996). The inflorescence is a terminal spike, 8-32 cm long (**Fig. 3**), drooping, dense, cylindrical lobed, borne on a thin and very short pedicel (Sundararaj and Thulasidas 1976). Each spikelet consists of a pair of glumes that embraces two minute flowers. The lower one is sterile whereas the upper one is fertile or bisexual with three stamens and a long oval smooth ovary with two long styles ends feathery (Nirmalakumari and Vetriventhan 2010). The anthers are yellow or white, ovary surmounted by two long

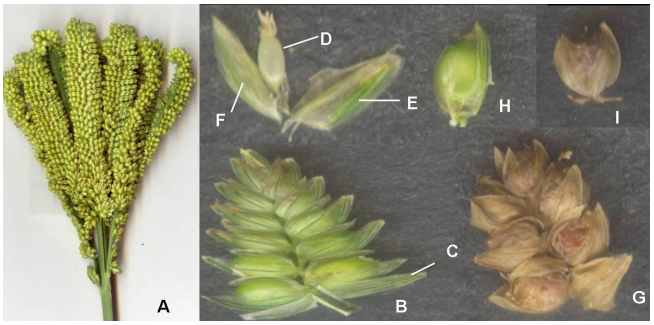

Fig. 2 Inflorescence and spikelet of finger millet. (**A**) Inflorescence; (**B**) Spikelet of finger millet; (**C**) Outer glume; (**D**) Ovary; (**E**) Lemma; (**F**) Palea; (**G**) Matured spikelet; (**H**) Grain with in lemma and palea; (**I**) Matured grain with in lemma and palea.

Fig. 3 Foxtail millet inflorescence and its parts. (**A**) Foxtail inflorescence; (**B**) Spikelet's cluster; (**C**) Subtended spikelet; (**D**) Opened spikelet; (**E**) Outer glume; (**F**) Grain enclosed in lemma and palea; (**G**) Grain.

Fig. 4 Proso millet inflorescence and its parts. (**A**) Inflorescence; (**B**) Opened spikelet; (**C**) Outer glume; (**D**) Inner glume; (**E**) Inner lemma; (**F**) Palea; (**G**) Inner glume; (**H**) Outer glume; (**I**) Upper lemma; (**J**) Anther; (**K**) Grain enclosed in lemma and palea; (**L**) Grain.

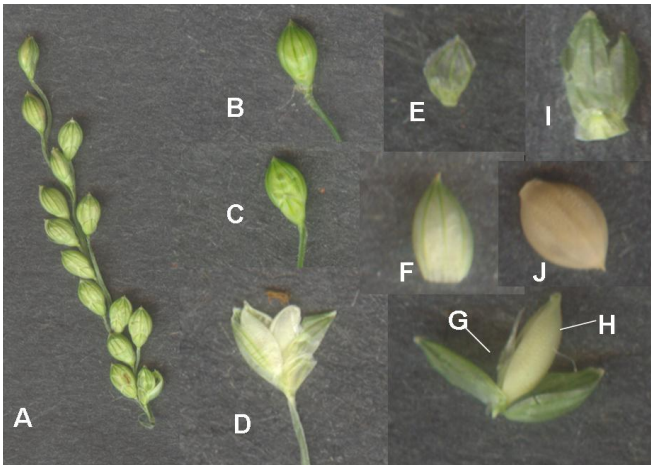

Fig. 5 Little millet inflorescence and its parts. (**A**) Inflorescence; (**B**) Spikelet; (**C**) Side view of spikelet; (**D**) Opened spikelet; (**E**) Outer glume; (**F**) First lemma; (**G**) Sterile floret; (**H**) Fertile floret; (**I**) Upper glume; (**J**) Grain enclosed in lemma and palea.

styles and feathery stigmas (Jayaraman *et al.* 1997).The lodicules are two in number. The grain is oval in shape, shiny, 2 mm in length, tightly enclosed within the thickened lemma and palea; varying in colour from cream to orange, yellow brown to black (Seetharam *et al.* 2003).

Anthesis and pollination

The flowers below the apex of the head begin to open when about three-fourth of the head emerges out of the sheath,. Flowering proceeds from the top to downward in the main spike (Sundararaj and Thulasidas 1976). A head takes 8 to 16 days to complete flowering. A single floret remains open for about 30 minutes, and it may take about 80 minutes for complete blooming, which is hastened by high temperatures and low humidity (Malm and Rachie 1971). During pollination tips of stigmatic branches and the anthers protrude through the slit between the incurved edges of the palea. The stigmatic branches emerge first followed by emergence of anthers. The anther after emergence starts dehiscing by longitudinal slits from the top to bottom (Sundararaj and Thulasidas 1976). As the glumes began to spread, the stigmas and the anthers developed and pushed out of the slit between the incurved edges of the palea. The feather like stigmas were first to emerge, but were quickly followed and overtaken by the anthers. Sometimes, some anthers remained adhered in the curved edges of the palea. This pattern is generally associated with round shaped flowers or moisture deficient soil (Siles *et al.* 2001). In general, the anthers shed pollen after they are fully extruded outside the glumes. After dehiscence, the glumes began to close, leaving the shriveled anthers and the tip of the stigmas outside. After pollination, the lodicules shrink and glumes begin to close. Anthesis in foxtail millet generally takes place near midnight and in the morning, but varies significantly with the environment (Siles *et al.* 2001). Most of the flowers opens during the midnight and between 8-10 a.m. (Jayaraman *et al.* 1997). The duration for an ear head to complete its flowering varies from 10-15 days. Maximum number of floret opens on sixth day of emergence (Sundararaj and Thulasidas 1976). Humidity and temperature are the main factors that affect pollination.

The foxtail millet is highly autogamous and the extent of out crossing varies from 1.4-4% (Li *et al.* 1935; Till-Bottraud *et al.* 1992). Natural crossing occurs between the cultivated and the wild taxa of foxtail millet, derivatives of such hybrids are obnoxious weeds (Rao *et al.* 1987). In general, tetraploids are more vigorous but colchicines induced auto-tetraploids in foxtail millet were smaller, late in flowering and had a two-fold reduced level of fertility (Ahanchede *et al.* 2004). However in another study 20% increase in grain weight was observed in polyploids, but the total grain yield decreased by 46% (Siles *et al.* 2004). A genetic male sterile line controlled by dominant gene 'Ch A' (Hu *et al.* 1986) and photoperiod sensitive male sterility (Cui *et al.* 1991) are being used in hybridization programme in China.

PROSO MILLET (*Panicum miliaceum* L.)

Proso millet is a widely cultivated as a cereal crop across the India, Nepal, West Burma, Sri Lanka, Pakistan and other South-East-Asian countries. It is a short duration crop and matures in 60-90 days after planting (Gupta and Gupta 2007) and highly tolerant to heat and drought. It is preferred for extreme soil and climatic conditions as it yields reasonably well even in degraded soils under unfavorable weather conditions (Baltensperger 2002). It has wide range of adaptation from hot summers in tropics to high altitudes areas of the Himalaya, where crop growing season is short (Sahib 1997). The protein content of proso millet is superior to rice and comparable to wheat (Gupta *et al.* 2010). The proso millet is a rich source of essential amino acid namely leucine, isoleucine and methionine, hence the protein quality of proso millet is considered better than wheat (Kalinova and Moudry 2006).

Floral morphology

Proso millet inflorescence is a - drooping panicle, 10-45 cm long that may be open or compact (Hulse *et al.* 1980), primary branches spreading or ascending or appressed, terminating in a spikelet. The bristles below the spikelets are absent. The spikelets are generally solitary and about 0.5 cm long (Gowda *et al.* 2003). Each spikelet contains two glumes and two lemmas. The glumes are unequal in length, outer glume is short, while the inner glume is as long as the spikelet. Each lemma contains one floret. The floret in lower lemma is sterile without stamen; upper lemma is fertile and shorter than lower lemma (**Fig. 4**). The palea of lower lemma (sterile floret) is very much reduced, while the palea of upper lemma (fertile floret) is well present (Seetharam *et al.* 2003). It has three stamens; anthers are tan or amber or blackish or dark brown in colour. The ovary has bifid style and plumose stigmas (Nanda and Agrawal 2008).

Anthesis and pollination

Proso millet starts flowering from top to downward to the bottom of the panicle (Sundararaj and Thulasidas 1976). The timing of anthesis in proso millet between 10.00 a.m. and 12 noon (Jayaraman *et al.* 1997). It takes 12-15 days from the start of the anthesis of the first flower to the last floret on the panicle. In proso millet, the receptivity of stigma coincides with the shedding of pollen from anthers. Nelson (1984) observed that when the florets were open, the anthers were sticky and pollen did not shed. Within minutes after the opening of florets, the anthers dried out and begin to shed pollen. The florets remain open for 10-15 minutes. The factors such as high temperatures, low humidity and bright sunlight promote the flowering. Flowering gets reduced on cloudy days. It can be stimulated by heating a panicle with lens. Proso millet ($2n$ = 36) is a self-pollinated crop, but natural cross-pollination may exceed 10% (Popov 1946).

LITTLE MILLET (*Panicum sumatrense* Roth ex Roem. & Schult)

Little millet is an important crop grown for food and feed in the tribal belt of Madhya Pradesh, Chattisgarh and Andhra Pradesh in India (Haider 1997). It is described as a quick growing, short duration cereal, which can withstand both drought and water logging (Doggett 1989).

Floral morphology

Little millet inflorescence is a panicle, contracted or thyrsiform and 15-45 cm in long and 1-5 cm in wide (Seetharam *et al.* 2003). The spikelet is persistent and 2-3.5 mm long (Bor 1960). Panicle branches are scabrous and drooping at the time of maturity. Spikelets produce on unequal pedicels but solitary at the end of the branches. Each spikelet consists of two minute flowers. The lower one is sterile; the upper one is fertile or bisexual without rachilla extension. The lemma I and its palea encloses the staminate or sterile flower; lemma II and its palea encloses the fertile flower (Sundararaj and Thulasidas 1976). Spikelets are elliptical, dorsally compressed, acute. It has three anthers about 1.5 mm in length. The Glume reaching apex of florets, thinner than fertile lemma (**Fig. 5**); lower glume is ovate, 0.7-1.2 mm long, membranous, without keels, 1-3 veined. The lateral vein is absent in lower glume and its apex is acute. The upper glume is also ovate and without keel but larger than lower glume. It has 11-15 veined (Nanda and Agrawal 2008).

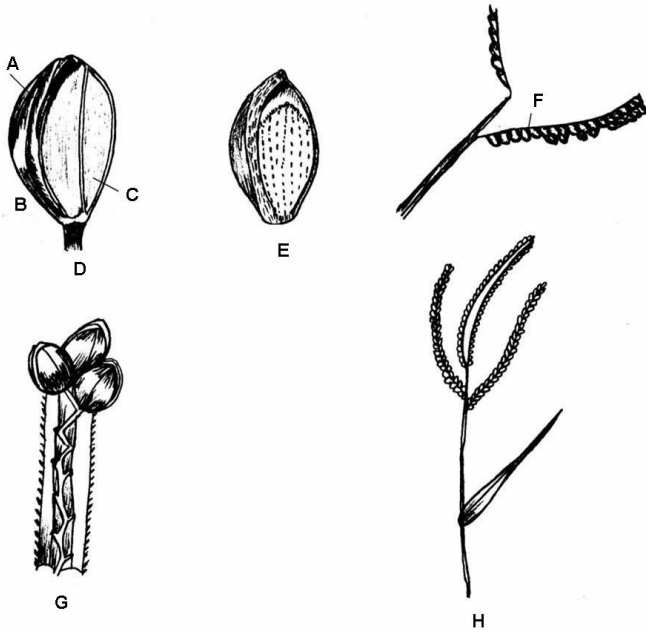

Fig. 6 Kodo millet inflorescence and its parts. (**A**) Upper floret; (**B**) Second glume; (**C**) Lemma of lower floret; (**D**) Spikelet; (**E**) Floret; (**F**) Rachis; (**G**) Arrangement of rachis in spikelet; (**H**) Inflorescence. (Source: **Nanda JS, Agrawal PK** (2008) *Botany of Field Crops* (Vol 1), Kalyani Publisher, India, 381 pp, with kind permission from the authors and publisher).

Anthesis and pollination

The opening of the spikelets commence from the second or third day after the appearance of the panicle. The flowering progresses from the top to the bottom of the panicle. The maximum numbers of flowers open on sixth or seventh day. It takes about a fortnight to complete the flowering in a panicle (Sundararaj and Thulasidas 1976). The anthesis occurs between 9.30 to 10.30 a.m. (Jayaraman *et al.* 1997). The glumes open for a short while and self pollination is the rule (Seetharam *et al.* 2003). The whole process of the anthesis is very rapid and is completed within 2-5 min.

KODO MILLET (Paspalum scrobiculatum L.)

Kodo millet is grown as a cereal in India only. Kodo millet is a long duration crop and grows well in shallow as well as deep soils (Hegde and Gowda 1989).

Floral morphology

Kodo millet inflorescence comprises of 2-6 racemes spreading widely on a sub-digitate or a short axis (**Fig. 6**). The racemes are 3-15 cm long (Seetharam *et al.* 2003). 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.

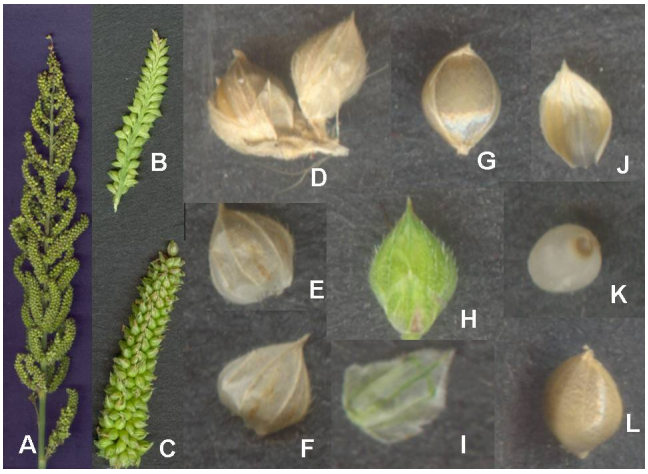

Fig. 7 Barnyard millet inflorescence and its parts. (**A**) Inflorescence; (**B**) Arrangement of spikelet in raceme; (**C**) Raceme; (**D**) Spikelet; (**E**) Lower lemma; (**F**) Upper glume; (**G**) Side view of fertile lemma enclosing grain; (**H**) View of spikelet from lower glume side; (**I**) Lower glume; (**J**) Fertile lemma; (**K**) Grain; (**L**) Grain enclosed in lemma and palea.

BARNYARD MILLET (*Echinochloa frumentacea* Link.)

Barnyard millet is grown in India, Japan and China as a substitute for rice under natural precipitation. It has a wide adaptation capacity and grown up to an altitude of 2000 m above mean sea level during summer season (Gupta *et al.* 2009). Among small millets, barnyard millet is the fastest growing millet and produces a crop in 6 weeks from sowing to maturity (Padulosi *et al.* 2009). The plant has attracted some attention as a fodder crop in the United States and Japan (Nirmalakumari and Vetriventhan 2009).

Floral morphology

Barnyard millet inflorescence is usually erect, rarely drooping terminal panicle. The racemes are few to numerous, densely crowded at the apex with spikelets arranged in 4 irregular rows on the triquetrous rachis. The spikelets are two-flowered, 2-3 mm long, ovate to elliptical, lower lemma awnless (**Fig. 7**) but sharp pointed, sub-sessile, and placed on short rough pedicels subtended by two glumes (De Wet *et al.* 1983). The lower glume is about one third of spikelet, while upper glume is somewhat shorter than spikelet. The glumes and lower lemma are slightly pubescent. The lower floret is neuter (sterile) having lemma and small palea, while upper floret is bisexual (Gupta *et al.* 2010). The sterile lemma is 5-veined. The fertile lemma is planoconvex, elliptic, smooth and shiny, abruptly sharp-pointed or cuspidate, margins are inrolled below over palea with apex of palea not being enclosed. The palea is flat and surface texture is similar to fertile lemma (Napper 1965). The stamens are three in number, ovary superior contains two distinct styles with plumose stigma (Sundararaj and Thulasidas 1976). The grain is tightly enclosed in white shinning hardened lemma and palea.

Anthesis and pollination

The flower opens in the upper raceme first and flowering is from the top of inflorescence to downwards. The panicle takes 10-14 days for emergence and takes 10-15 for completion of flowering under the hill conditions. The maximum number of florets opens during 6-8 days after flowering (Sundararaj and Thulasidas 1976). Flowers open from 5-10 a.m. with maximum number of flower opens between 6-7 a.m. (Jayaraman *et al.* 1997; Sundararaj and Thulasidas 1976). Within a individual raceme the flowering first starts at both the marginal ends first and then proceed to the middle of the raceme. Before the anthers dehiscence, the stigmatic branches spread and flower opens (Seetharam *et al.* 2003). The flower closes within half an hour. It is highly self-pollinated species. Hot water treatment of inflorescence at 48°C for 4-5 min (pers. obs.) was also found effective in inducing male sterility under hill condition in barnyard millet.

CONCLUSION

Small millets are highly self-pollinated and relatively low level of improvement in small millets appears to be the consequence because of difficulties in emasculation and hybridization. Hence, inducing male sterility is one of the ways for effective hybridization and enhancing out-crossing for improvement in these crops.

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