

REPRODUCTIVE BIOLOGY, BREEDING BEHAVIOR, EMASCULATION & POLLINATION TECHNIQUES IN FOXTAIL MILLET (*SETARIA ITALICA*)

Abstract

Millets are a group of small grained cereals. These crops largely contribute to food and nutritional security of the country. They are good for consumer, farmer and planet. Foxtail millet is believed to be originated in China. At present in India, foxtail millet is cultivated on a limited area in Karnataka, Telangana, Andhra Pradesh, Maharashtra, Tamil Nadu. Foxtail millet has high content of minerals, non-starchy polysaccharides, vital amino acids, proteins and hence it is regarded as one of the world's most important Nutri cereals. The grain contains high protein (14-16%), fat (5-8%). Nutritional superiority of foxtail millet grain is also shown by more edible fibre content (2.5-fold) and the bran has 9.4% crude oil containing 66.5% linoleic and 13.0% oleic acid. It helps in proper functioning of nervous system, protect bone health and muscle health, good for cardiac health, regulates blood sugar level, lowering blood cholesterol, helps in good digestion, helps for weight loss, improves immunity. Foxtail millet has a slender, erect, leafy stem with dense root system. It is drought tolerant. The inflorescence of foxtail millet has a main stalk with shortened side branches bearing spikes and bristles. The inflorescence is a terminal spike. The duration for an ear head to complete its flowering varies from 10-15 days. The foxtail millet is highly autogamous and the extent of out crossing varies from 1.4-4%. The difficulty in making crosses artificially and lack of an efficient crossing technique have resulted in a very limited number of genetic studies and limited improvement of foxtail millet. The most commonly followed method to make crosses is hot water emasculation followed by contact method and hand emasculation followed by pollination.

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I. INTRODUCTION

- Millets are a collection of small-grained cereal food crops known for their exceptional nutritional value.
- They thrive in marginal and less fertile soils, requiring minimal use of fertilizers and pesticides.
- These crops play a significant role in enhancing food and nutritional security within the country.
- Millets are smart foods.
- They are Good for consumer, Good for farmer, Good for planet.
- Millets, classified under the Poaceae family, exhibit a diverse range of characteristics, including variations in shape, size, and color. Among the different types of millets found in various countries are kodo millet (*Paspalum scrobiculatum* L.), pearl millet (*Pennisetum glaucum*), barnyard millet (*Echinochloa esculenta*), finger millet (*Eleusine coracana* L.), little millet (*Panicum sumatrense*), proso millet (*Panicum miliaceum* L.), and foxtail millet (*Setaria italica* L.) P. Beauv. (Neeraja et al. 2017; Garg et al. 2018; Kumar et al. 2018).
- Millets are abundant in essential nutrients, proteins, and various minerals, with approximately 80% of millet grains utilized as food, while the remaining 20% serves as feed and for industrial purposes (Shivran 2016; Kumar et al. 2018).
- Millets are highly regarded as a nutritious option for newborns, lactating mothers, convalescents, and the elderly.
- The slow release of sugar into the bloodstream from millet grains makes them a gluten-free option (Arendt and Bello 2008).
- The high protein and fiber content of millets have led to a surge in demand, making them a favored dietary choice for individuals with cardiovascular diseases and diabetes (Arendt and Bello 2008).

1. Taxonomy

Foxtail millet $2n = 2x = 18$

- Kingdom : Plantae
- Sub kingdom : Tracheobionta
- Super division : Spermatophyta
- Division : Magnoliophyta
- Class : Liliopsida
- Subclass : Commelinidae
- Order : Cyperales
- Family : Poaceae
- Genus : *Setaria*
- Species : *italica*

2. Origin and Distribution

- Foxtail millet (*Setaria italica* L.) Beauv.) holds historical significance as one of the earliest cultivated millets.

- Its domestication traces back to China around 8700 years ago, making it one of the world's oldest cultivated crops (*Yang et al., 2012; Goron and Raizada, 2015*). During the Neolithic culture in China, foxtail millet played a pivotal role as a primary food source. Its cultivation in Russia also dates back to ancient times, with evidence of its presence as long as 1500 years ago.
- East Asia, particularly China and Japan, is recognized as the principal center of diversity for foxtail millet, according to Vavilov (1926). Nevertheless, due to its cultivation in Europe approximately 4000 years ago, multiple domestication hypotheses have gained acceptance. Foxtail millet exhibits adaptability, thriving across various altitudes ranging from sea level to 2000 meters.

3. Area Production Productivity

- Foxtail millet holds the second position globally in terms of millet production, contributing significantly to the total millet output worldwide. The estimated cultivated area for foxtail millet on a global scale is approximately 10.57 lakh hectares, yielding around 22.9 lakh metric tons of grains.
- In India, foxtail millet is currently grown in limited regions, including Karnataka, Telangana, Andhra Pradesh, Maharashtra, Tamil Nadu, Rajasthan, Madhya Pradesh, Uttar Pradesh, and the northeastern states. During the 2005-06 period, the cultivated area for foxtail millet in India covered about 0.98 lakh hectares, resulting in a grain production of approximately 0.56 lakh metric tons, with an average productivity of 565 kg/ha.
- Subsequently, in the year 2015-16, the estimated cultivated area decreased to 0.87 lakh hectares, but the production increased to 0.66 lakh metric tons, with a productivity of 762 kg/ha.
- Despite being the third-largest producer of foxtail millet globally, India's contribution to the world's foxtail millet production stands at 2.2%.

4. Nutritional Importance

- Foxtail millet is considered one of the world's most important nutriceals due to its high content of minerals, non-starchy polysaccharides, vital amino acids, and proteins (*Gowda et al., 2022*).
- The primary carbohydrate in foxtail millet is starch, constituting up to 60% of its dry weight.
- Foxtail millet contains both amylose (25%) and amylopectin (up to 75%), with the unique linear structure of amylose and the branched structure of amylopectin contributing to its nutritive quality.
- Key amino acids found in foxtail millet include methionine, valine, and lysine.

- Compared to other cereals, foxtail millet has a high protein content (14–16%), significant fat content (5–8%), and abundant minerals (*Thathola et al., 2011; Ravindran, 1992*).
- Foxtail millet's digestible protein contains a majority of the essential amino acids, surpassing major cereal crops like rice and wheat (*Zhang et al., 2007*).
- Foxtail millet exhibits nutritional superiority with its higher edible fiber content (2.5 times) and bran containing 9.4% crude oil, including 66.5% linoleic acid and 13.0% oleic acid (*Liang et al., 2010; Black et al., 2013*).

5. Health Benefits

- Supports the healthy functioning of the nervous system.
- Promotes strong bones and muscles.
- Beneficial for heart health.
- Helps regulate blood sugar levels.
- Assists in reducing blood cholesterol levels.
- Supports good digestion.
- Aids in weight loss efforts.
- Boosts immunity.

II. MORPHOLOGICAL DESCRIPTION

- Foxtail millet exhibits a slender, upright stem with a height ranging from 30 to 150 cm.
- At maturity, the stem tends to bend due to the weight of the earhead.
- The number of tillers varies based on the genotype and race, ranging from a few to many.
- The leaves are narrow, measuring approximately 30-45 cm in length and 1.25 cm in width, displaying a green color.
- The plant features a dense root system, thick cell walls, and specific arrangements of epidermal cells, resulting in minuscule leaf areas.
- Foxtail millet is known for its drought tolerance, although its recovery after prolonged drought spells is relatively poor.

1. Floral Morphology

- The inflorescence of foxtail millet comprises a central main stalk with shortened side branches, bearing spikes and bristles (*Baltensperger, 1996*).
- The terminal spike is drooping, dense, and cylindrical with lobed structures, measuring 8-32 cm in length, and is supported by a thin, very short pedicel (*Sundararaj and Thulasidas, 1976*).
- Each spikelet contains a pair of glumes that embrace two minute flowers. The lower flower is sterile, while the upper flower is fertile or bisexual, featuring three stamens and a long oval smooth ovary with two long styles ending in feathery structures

(*Nirmalakumari and Vetriventhan, 2010*).

- The anthers are yellow or white, and the ovary is topped by two long styles with feathery stigmas (*Jayaraman et al., 1997*).
- The millet's structure includes two lodicules.
- Foxtail millet grains are oval, shiny, measuring about 2 mm in length, and tightly enclosed within thickened lemma and palea structures. They come in various colors, ranging from cream to orange, yellow-brown to black (*Seetharam et al., 2003*).

III. ANTHESIS & POLLINATION BEHAVIOR

1. Flowering in foxtail millet commences when approximately three-fourths of the head emerges from the sheath, progressing from the top to the bottom of the main spike (*Sundararaj and Thulasidas, 1976*).
2. The flowering process of a single head takes about 8 to 16 days. Each floret remains open for around 30 minutes, with complete blooming occurring in approximately 80 minutes, expedited by high temperatures and low humidity (*Malm and Rachie, 1971*).
3. During pollination, stigmatic branches and anthers protrude through the slit between the incurved edges of the palea. Stigmatic branches emerge first, followed by anther emergence. Anthers dehisce through longitudinal slits from top to bottom after emergence (*Sundararaj and Thulasidas, 1976*).
4. As the glumes spread, stigmas and anthers develop and are pushed out of the slit between the palea's incurved edges. Anthers may sometimes remain adhered to the curved edges of the palea, particularly in round-shaped flowers or moisture-deficient soil conditions (*Siles et al., 2001*).
5. Anthers generally shed pollen after they fully emerge outside the glumes. After dehiscence, the glumes begin to close, leaving the shriveled anthers and the tip of the stigmas outside.
6. Foxtail millet's anthesis typically occurs near midnight and in the morning, although the timing varies with environmental factors (*Siles et al., 2001*). Most flowers open during midnight and between 8-10 a.m. (*Jayaraman et al., 1997*).
7. The duration for an ear head to complete its flowering ranges from 10 to 15 days, with the maximum number of florets opening on the sixth day after emergence (*Sundararaj and Thulasidas, 1976*).
8. Humidity and temperature play significant roles in affecting pollination.
9. Foxtail millet is highly autogamous, with outcrossing varying from 1.4% to 4%.
10. Natural crossing occurs between cultivated and wild foxtail millet taxa, and hybrids resulting from such crosses can become invasive weeds (*Rao et al., 1987*).

11. Polyploids in foxtail millet generally exhibit increased vigor, but colchicine-induced autotetraploids showed reduced size, delayed flowering, and a two-fold reduction in fertility (*Ahanchede et al., 2004*). However, another study reported a 20% increase in grain weight in polyploids, although the total grain yield decreased by 46% (*Siles et al., 2004*).
12. Genetic male sterile lines controlled by the dominant gene 'Ch A' (*Hu et al., 1986*) and photoperiod-sensitive male sterility (*Cui et al., 1991*) are utilized in hybridization programs in China.

IV. EMASCULATION & HYBRIDIZATION

1. Foxtail millet's limited genetic studies and improvements can be attributed to the challenging process of making artificial crosses and the lack of an efficient crossing technique.
2. The minute size of the spikelet poses difficulties in manual manipulations, such as hand emasculation.
3. *Siles et al. (2001)* presented an artificial hybridization technique that resulted in 67.5% successful hybrid seed set per flower crossed.
4. The technique involved isolating the female parent and removing the bristles of both male and female parents gently using scissors.
5. Emasculation was performed when the first anther had just emerged and before the pollen sacs burst.
6. Using fine forceps and magnifying glasses, the three anthers were carefully removed. If the anthers were not fully extruded, gentle forceps insertion at each side of the palea quickly pushed them out.
7. The emasculated flower was marked for identification, and unmarked flowers were removed. The panicle was then covered with a butter paper bag.
8. Pollination was immediately conducted by placing the emasculated panicle below the male panicle that had begun shedding pollen and covering both panicles together.
9. The pollen shed from the male panicle allowed fertilization of the emasculated spikelet.
10. Gentle shaking of the panicles together for 2 days during anthesis allowed the stigmas, which remain outside the glumes and receptive for 48 hours, the opportunity for fertilization.
11. On the third day, the male panicle was carefully removed, and the emasculated panicle was checked for any later-developing florets by identifying the absence of a mark. Any such florets were removed.
12. The female panicle was then covered again and maintained until maturity (*Siles et al., 2001*).

The most commonly followed method to make crosses is hot water emasculation followed by contact method –

- Emasculation is performed during the evening hours.
- Identify the female panicle where anthesis has already begun at the tip and the upper portion.
- Select a few lobes with well-developed spikelets that will open the next day.

- Remove the remaining lobes from the bottom and other sides of the selected spikelet using scissors.
- Thin out the spikelet if the lobe is dense and remove bristles that may obstruct pollen flow.
- Immerse the female panicle in hot water maintained at 48-50°C for 2 minutes and then cover it with a butter paper bag.
- The next morning, pollination is conducted using the contact method.
- Select a male panicle that is about to open and cut it with a long stalk from the plant.
- Bring the male panicle close to the emasculated panicle and tie them together using twine, then cover with a butter paper bag.
- To prevent drying of the male panicle, immerse its cut end in water kept in a bottle test tube.
- Natural cross-pollination occurs within 2 to 5 days. Gentle shaking in the morning hours can promote pollen dispersal.
- Alternatively, if parents are grown in pots, they can be brought together, and the male panicle and hot water-treated female panicle can be tied together and covered with a butter paper bag. After 5 days when anthesis is complete, the male panicle can be removed.
- At maturity, carefully harvest the seeds from the emasculated panicle.
- The contact method can also be applied in the field by planting parents in paired rows and adjusting sowing dates for flowering synchronization.

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