**Reproductive biology, breeding behavior, emasculation & pollination techniques in foxtail millet *(Setaria italica)***

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## Introduction: -

### Millets are group of small grained cereal food crops which are highly nutritious.

### Millets are grown under marginal and low fertile soils with very low inputs such as fertilizers and pesticides.

### These crops largely contribute to food and nutritional security of the country.

### Millets are smart foods

### Good for consumer, Good for farmer, Good for planet

### Millets belong to the family Poaceae and vary in shape, size and color. Several types of millets such as; kodo millet *(Paspalum scrobiculatum L.*), pearl millet (*Penniisetum glaucum*), barnyard millet (*Echinochloa esculenta*), finger millet (*Eleusine coracana* (L.), little millet (*Panicum sumatrense*), proso millet (*Panicum miliaceum* L.), foxtail millet (*Setaria italica* (L.) P. Beauv) are indigenous to several countries *(Neeraja et al. 2017; Garg et al. 2018; Kumar et al. 2018).*

### Millets are rich in different nutrients, proteins, and various minerals, and almost 80% of millet grains are used as food while 20% is utilized for feed and industry (Shivran 2016; Kumar *et al*. 2018).

### Millets are considered as ideal nutrition for newborn children, lactating mothers, convalescents and old.

### The grains dissipate sugar gradually into the circulatory system and are considered “sans gluten” (Arendt and Bello 2008).

### There is a high demand for the millets due to rich protein and high fiber content which favored them as dietary nourishment for individuals with cardiovascular sicknesses and diabetes (Arendt and Bello 2008).

### 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*

### Origin and Distribution

### Foxtail millet [*Setaria italica* (L.) Beauv.] is one of the oldest of the cultivated millets.

### Foxtail millet is reported to have been domesticated in China almost 8700 years ago and is regarded as one of the world’s oldest crops *(Yang et al. 2012; Goron and Raizada 2015).*

### Foxtail millet was the most important plant food in the Neolithic culture in China.

### In Russia foxtail millet has been cultivated since ancient times and there is evidence that it was grown as long as 1500 years ago.

### According to Vavilov (1926), the principal centre of diversity for foxtail millet is East Asia, including China and Japan.

### However, multiple domestication hypotheses has been widely accepted because of its cultivation about 4000 years ago at Europe. Foxtail millet can grow in attitudes from sea level to 2000 m.

### Area production productivity

### Foxtail millet ranks second among the millet produced globally world’s total production of millets. The world area under foxtail millet is estimated to be 10.57 lakh ha producing 22.9 lakh tones of grains.

### In India at present, foxtail millet is cultivated on a limited area in Karnataka, Telangana, Andhra Pradesh Maharashtra Tamil Nadu. Rajasthan Madhya Pradesh Uttar Pradesh and north eastern states.

### Foxtail millet was grown in an area of 0.98 lakh ha during 2005-06 producing about 0.56 lakh tones of grains with an average productivity of 565 kg/ha

### The estimated area during 2015-16 was 0.87 lakh ha with a production of 0.66 lakh tones and productivity of 762 kg/ha.

### India ranks 3 in terms of production, contributing only 2.2% to the world foxtail millet production.

### Nutritional Importance

### Foxtail millet has high content of minerals, non-starchy polysaccharides, vital amino acids, and proteins, and hence it is regarded as one of the world’s most important nutricereals (*Gowda et al. 2022).*

### The main carbohydrate present in foxtail millet is starch and it contributes up to 60% of dry weight.

### Amylose makes up 25% and amylopectin, up to 75%. The linear structure of amylose and the amylo pectin’s branched structure contribute to the millet’s unique nutritive quality.

### The major amino acids present in foxtail millet are methionine, valine and lysine.

### The grain composition of foxtail millet has high protein (14–16%), fat (5–8%) and minerals as compared to cereals (*Thathola et al. 2011; Ravindran 1992*).

### Further, digestible protein also has majority of the essential amino acids compared to major cereal crops such as rice and wheat (*Zhang et al. 2007*).

### Nutritional superiority of foxtail millet grain is also shown by more edible fiber content (2.5 fold) and the bran has 9.4% crude oil containing 66.5% linoleic and 13.0% oleic acid (*Liang et al. 2010; Black et al. 2013)*

### Health benefits

### Helps in proper functioning of nervous system

### Protects 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

### Morphological description

### Foxtail millet has a slender, erect, delicate stem varying in height from 30-150 cm.

### The stem bends quite a bit at maturity due to heavy weight of earhead.

### The numbers of tillers vary from a few to many depending on the genotype and race. Leaves are narrow (30-45 cm long and 1.25 cm wide) and green in color.

### It has dense root system, thick cell walls, epidermal cell arrangements and minuscule leaf areas.

### It is drought tolerant, but recovery is poor after a prolonged drought spell.

### 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, 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 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 & Pollination Behavior

### 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%

### 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.

### Emasculation & Hybridization

### Hand Emasculation followed by Pollination

### 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 minute size of spikelet makes it difficult for any manipulation with respect to hand emasculation.

### *Siles et al (2001*) described an artificial technique of hybridization that resulted in 67.5% hybrid seed sat per flower crossed.

### The technique involved removal of anthers as soon as anthesis starts in the early morning after isolation of female parent.

### The bristles of male and female parent were excised gently with a pair of scissors first.

### Emasculation was done when the first anther had just emerged and before the pollen sacs had burst.

### The three anthers were carefully removed using a fine forceps with the help of magnifying glasses.

### If the anthers were not fully pushed out, the anthers were removed by gently inserting the forceps at each side of the pales and pushing the anther out quickly.

### The emasculated flower was marked immediately for identification.

### After emasculation is over, all the unmarked flowers were removed and panicle was covered with a butter paper bag Pollination was immediately done by bringing the emasculated panicle below the male panicle that has started shedding pollen and covering both the panicles together.

### The pollen shed from the male panicle provides opportunity for fertilization of emasculated spikelet.

### The panicles were shaken together gently for 2 days during the period of anthesis . As the stigmas remain outside the glumes and are receptive for 48 h the shaking process provides opportunity for fertilization.

### On the 3 day the male panicle was carefully removed and emasculated panicle was carefully checked for any floret that may have developed later. Such florets were removed by identifying the absence of mark. The female panicle was covered again and maintained till maturity (*Siles et al., 2001*).

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

### The emasculation is done during the evening hours.

### In this select the female panicle which has past started anthesis at the tip and out the to portion

### Select only a few lobes containing well developed spikelets which will open the next day.

### Remove the remaining lobes from the button as well on the other side of the selected spikelet using a pair of scissors.

### Thin out the spikelet from the selected lobe in case of a dense lobe. Also to move the bristles which will prevent free flow of pollen,

### Dip the female panicle in hot water maintained at 48-50 °C for 2 minutes. Then take out the panicle and cover with a butter paper bag.

### The pollination in done in the next morning following contact method.

### Select the male panicle which will be opened and cut with long stalk from the plant.

### Bring this panicle to the emasculated panicle and be the whole male panicle with female panicle using twine.

### Cover with butter paper bag.

### Immerse the cut end of the male panicle in water kept in a bottle test tube to prevent drying of male panicle,

### Natural cross pollination takes place in 2 to 5 days.

### A gentle shaking can be given in the morning hours to promote pollen dispersal.

### Alternatively, if the parents are grown in pots the pots can be brought together and male panicle and hot water treated female particle can be tied together and covered with butter paper bag After 5 days when the anthesis will be over the male panicle can be removed.

### At maturity carefully harvest the seeds from emasculated panicle.

### Contact method can also be followed in the field by planting the parents in paired rows and adjusting the sowing dates for flowering synchronization.

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