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EVALUATION OF GROWTH, FLORAL BIOLOGY, YIELD AND SEED QUALITY TRAITS OF FOXTAIL MILLET (*SETARIA ITALICA* L.) IN THE UTTARAKHAND HILL AGRO-ECOSYSTEM

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ABSTRACT

The study was conducted on foxtail millet variety SIA-3156, in the year 2023 during *kharif* season (June – September) at Department of Seed Science and Technology, Srinagar Garhwal. Seeds were sown during the first week of June in plots measuring 3 × 4 m. Morphological and growth parameters were recorded at different growth stages throughout the crop period. The floral biology of foxtail millet was studied with emphasis on reproductive structures, flowering behaviour, and pollination mechanisms. Plant growth and development were assessed under field conditions based on field emergence and successive leaf emergence stages, including first, second, and third leaf appearance. Foxtail millet, being a short-duration crop, matured and was harvested at 95 days after sowing (DAS). After harvest, seeds were properly cleaned and dried for further evaluation. Seed vigour parameters such as germination percentage, seedling length, and seedling dry weight are important indicators of seed quality. Variations in these parameters directly influence seed performance and subsequent crop establishment. Higher germination and vigorous seedling growth ensure better field emergence and plant development. Therefore, understanding the factors affecting seed vigour and predicting seed longevity is essential for maintaining seed quality. The availability of high-quality, vigorous seeds helps farmers achieve uniform crop stands, improved productivity, and ultimately enhanced food security.

***Key words*:** Foxtail millet, Floral biology, Crop growth stages, Agro-ecosystem, Seed quality, Seed vigour and Seed longevity

Introduction

Foxtail millet (*Setaria italica* L.) is a minor cereal crop belonging to family Poaceae, subfamily Panicoideae. It is also known as Italian millet (Moharil *et al*., 2019). is originated in China, at present foxtail millet is cultivated in 26 countries. In terms of yielding ability, foxtail millet rank 4th among all millets. It is world's second largest millet crop, use for cultivation in India, China, Africa, USA, Russia and some other part of Europe. Small stature, short life cycle, small diploid genome size, low-glycemic index, antioxidant properties and drought-tolerant features make foxtail millet a model grass (Brutnell *et al*., 2010). Foxtail millet has traditionally been cultivated for local use, and applications are limited to grazing, fodder, or silage.

Foxtail millet is an annual grass characterized by slender, erect, leafy stems that can attain a height of 120–200 cm (Swamy *et al*., 2023). The inflorescence is a spike with short side branches bearing spikelet's and bristles. Each spikelet consists of a pair of glumes that embrace two-minute flowers; the lower one sterile and the upper one is bisexual, with three stamens and a long oval smooth ovary with two long styles, which terminate in a brush like stigma (Gupta *et al*., 2011 and Hector, 1936). One to three bristles develop at the base of each spikelet (Vinall, 1924). Anthesis in foxtail millet generally takes place near midnight and in the morning but varies significantly with environment (Malm and Rachie, 1971).

The seed head is a dense, hairy panicle, 5–30 cm long. The seeds are small, about 2 mm in diameter. Seed color varies greatly among cultivars and ranges from pale yellow, through to orange, red, brown and black (Moharil *et al*., 2019).

Foxtail millet has many nutritional and health benefits. It have rich source of nutrients, minerals, fiber, protein and Phyto constituents (Yang *et al*., 2022). Antinutritional factors such as tannin and phytic acid are reduced by using suitable processing methods (Sharma *et al*., 2018). Foxtail millet is non-glutinous, and it is soothing and easy to digest. The grains are least allergenic compared to other available grains (Prashant *et al*., 2005). Millet bran is extensively used as animal feed in China (En *et al.*, 2008). Similar to other cereals, foxtail millet is deficient in lysine, with amino acid scores similar to corn. It is relatively high in leucine and methionine. The starch in some foxtail millet cultivars contain 100% amylopectin, and the starches contained in foxtail, proso and barnyard millets are more digestible than maize starch, because they release sugars slowly and thus have a low glycemic index (Moharil *et al*., 2019)

Material and Methods

Crop cultivation

Experiment was conducted at the department of Seed Science and Technology, HNB Garhwal, Uttarakhand with foxtail millet variety SIA-3156. Field experiment was conducted in randomized block design (RBD) with a spacing of 30 × 10 cm, row to row and plant to plant, respectively. The plot size was 3 × 4 m and replicated three times. Observations on field emergence, plant growth and development were recorded after field emergence to harvest maturity. Such as, days to field emergence, first leaf stage, second leaf stage, days to 50% flowering, 100 % flowering. Plant growth and development were also recorded at 45 DAS and 90 DAS, such as plant height, number of tillers, number of leaves, plant fresh weight and plant dry weight. After harvest grain yield, seed yield, vegetative yield, biomass and harvest index was recorded for plant^{-1}, m^{-2}, plot^{-1} and ha^{-1}.

Harvest and post-harvest operations

The crop was harvested on September 19, 2023. Harvesting was done once the earheads are physiologically mature. Normally crop is ready for harvest in 85 - 90 days after sowing. Physiologically mature earheads were start to dry. Plants are either harvested intact with earheads or earheads alone. Threshing was done by traditional method. Harvested crop spread on threshing floor and manually beating with the help of wooden stick. Winnowing was done by throwing the mixture of threshed seed into the air so that the wind blows away the lighter chaff, while the heavier seeds fall back down recovery. Seed cleaning was done by soaking seeds with water in bucket. After 5-minute immature seeds which were floating on the water, were separated and the mature seeds which sat in the water were separated. To remove hull, seeds were spread on the roof surface and rubbed with the help of thermocol sheet. After rubbing the seed was throw in the air to separate husk from seed. To uniform drying, the seeds were spread in thin layer for 4 to 5 hours in sun light.

Seed quality analysis

Moisture content (%):

Seed moisture content was determined by following gravimetric method. Five-gram seed was taken for determining seed moisture content (%) obtaining constant weight. The moisture content of seed (fresh weight basis) was determined by using formula (ISTA, 2017).

$$\text{Moisture content (mc)} = \frac{M2 - M3}{M2 - M1} \times 100$$

Where,

M1 - Wt. of the container and its cover (g),

M2 - Wt. of the container and its cover + wt. of seed sample before drying,

M3 - Wt. of the container and its cover + wt. of seed sample after drying.

Germination test:

Three replications of 100 seeds each were used to assess germination using the Top of Paper (TP) method. The seeds were placed on filter paper in Petri dishes, which were then covered with lids and kept in a germinator maintained at a constant temperature of 28 ± 1°C and 80–85% relative humidity. Germination percentage was calculated using the following formula.

$$\text{Germination (\%)} = \frac{\text{Total no. of normal seedling germinated}}{\text{Total no. of seeds used for germination test}} \times 100$$

Root length and shoot length:

On the final count of germination, ten normal seedlings were selected randomly from all the replications. Root length was measured from the base end of the steam to tip of the root and the mean root length was expressed in centimetre (cm). The length shoot of the same previously used ten seedlings was measured from the base of the first leaf to the tip and the mean shoot length was expressed in centimetre (cm).

Speed of germination:

Speed of germination expresses the rate of germination in terms of the total number of seeds that

germinate in a time interval. Speed of germination was calculated by the following formula (Maguire, 1962).

$$\text{Speed of germination} = \frac{n1}{d1} + \frac{n2}{d2} + \frac{n3}{d1} + \cdots + \frac{nx}{dx}$$

Where,

n = number of germinated seed,

d = number of days.

Seedling dry weight:

Ten normal seedlings from each replication used for seedling dry weight were put in small size glass Petri plates and kept in an oven maintained at 130 ^{0}C for 2 hours. After drying, the seedlings were kept in desiccators for cooling. The weight of dried seedlings was recorded and mean weight was calculated and expressed in grams (g) (Evans and Bhatt, 1977).

Seedling vigour index:

At the end of germination test ten normal seedling from each replication were selected for calculation of vigour index (Abdul Baki and Anderson, 1973) and calculated as under.

Seedling vigour index (SVI-I) = Germination % × Seedling length (cm)

Seedling vigour index (SVI-II) = Germination % × Seedling dry weight (g)

Electrical conductivity (EC) of seed leachate:

One-gram seed sample was taken and surface sterilized with 2% sodium hypochlorite for 2 minutes. After that the seeds were washed with double distilled water for 3- 4 times. The clean seeds were soaked in 25 ml double distilled water at 25±5 ^{0}C temperature for 24 hours. After this the seeds are removed with the help of clean strainer. The steep water left is decanted and is termed as leachate. The electrical conductivity of seed leachate from seeds that were intact or punctured was measured with a DDSJ-308A conductivity meter. Electrical conductivity (µS cm^{-1} g^{-1}) of the incubation solution was recorded following the procedure described by Sun, & Wang, (2018) and Hampton & TeKrony (1995).

Statistical analysis

Field experiments were laid out in a Randomized Block Design (RBD), whereas laboratory experiments were conducted using a Completely Randomized Design (CRD), following procedures was described by Gomez and Gomez (1984). Analysis of variance (ANOVA) was performed using statistical software which was developed by O. P. Sheoran, Computer Programmer, CCS Haryana Agricultural University, Hisar, India. The critical difference (CD) was calculated to test the significance of treatment effects.

Table 1: Various phenological stages in foxtail millet during *kharif* season 2023.

Various phenological stages	Days after sowing
50 % Field emergence	3
100 % Field emergence	5
Coleoptile emergence	3
First leaf stage	6
Second leaf stage	8
Third leafe stage	15
Booting stage	46
Flower initiation	48
50% flowering	61
100% Flowering	69
Anthesis	55

Results and Discussion

Plant growth and development

Plant growth and development was recorded, such as coleoptile emergence, first leaf emergence, second leaf emergence, third leaf emergence, booting stage, flower initiation, 50% flowering, 100% flowering and anthesis in term of days to complete the process. In foxtail millet coleoptile emergence was completed within three DAS, and first leaf emergence was recorded at six DAS, while second leaf emergence was recorded at eight DAS. Similar, pattern was recorded for three leaf emergence, which started at 15 DAS. Booting was recorded at 46 DAS and flowering was initiated at 48 DAS. On the other hand, the process of anthesis in foxtail millet started at 55 DAS. Further 50% flowering was completed within 61 DAS, while 100 % flowering occurred in 69 DAS (Table 1).

Plant growth was also recorded in foxtail millet variety SIA-3156 at 45 and 90 DAS, such as plant height, number of tillers, number of leaves, plant fresh weight and plant dry weight. Plant height was recorded 26.8 cm at 45 DAS, and 202.6 cm at 90 DAS. Similarly, number of tillers was recorded two at 45 and 90 DAS. Number of leaves was recorded six at 45 DAS and eight at 90 DAS. Further fresh weight of plant was recorded, 6.37 g at 45 DAS and 39.4 g at 90 DAS, while dry weight of plant was recorded, 1.08 g at 45 DAS and 21.55 g at 90 DAS. Critical difference for various growth stages were significant for the parameters recorded except for number of tillers and number of leaves (Table 2). The difference between 45 and 90 DAS, in plant growth such as plant height, number of tillers, number of leaves, plant fresh weight and plant dry weight. Difference was recorded; 175.8 cm in plant height (not shown in figure), two in

Table 2: Plant growth and development stages, i.e, plant height, number of tillers, number of leaves, plant fresh weight in foxtail millet at 45 and 90 day after sowing.

Parameters	45 DAS	90 DAS	C.D.	SE (m) ±
Plant height (cm)	26.8	202.6	25.5	3.89
Number of tillers	2	2	NS	0.47
Number of leaves	6	8	NS	0.62
Plant fresh weight (g plant^{-1})	6.37	39.4	6.22	0.95
Plant dry weight (g plant^{-1})	1.08	21.55	8.09	1.23

numbers of leaves, and 33.03 g in plant fresh weight and 20.47 g in plant dry weight, while there was no change in number of tillers during this period.

Floral biology of foxtail millet

Flower morphology and anthesis:

The inflorescence of foxtail millet is an erect or spike like bristly panicle. which having length 10-35 cm and width 2.5-4.5 cm. The inflorescence of foxtail millet variety SIA-3156 has different size and shapes, i.e, lax, medium, compact, oblong, pyramidal and cylindrical. Inflorescence is a cluster of spikes and each spike have 3-5 spikelets which consist one pair of glumes (outer and inner) and two bracts one is lemma and another is palea. Foxtail millet flower is bisexual with three stamens and pistil. The anther present in four lobed condition and dark brown in colour, while the pistil located in the center of the flower with sigma, style and ovary. Foxtail millet is highly autogamous crop and sequence of flower bud opening (anthesis) is top to bottom (basipetal) order in main spike and a head takes 8 to 16 days to complete flowering. Anthesis in foxtail millet generally takes place in the morning between 8-10 a.m, Similar results were reported by Gupta *et al.*, (2011).

Anther and Pollen structure:

The anther of foxtail millet present in dithecous and four lobes condition. Anther is dark brown in colour, however, yellowish colour is seen under the microscope after staining. Two thecae of anther connected by a connective. A large number of pollen grains seen inside the lobes of staining anther under microscope (Plate 1).

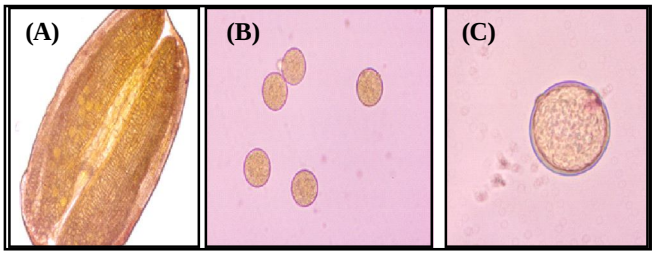

Plate 1: A- Anther lobs; B- Pollens of foxtail millet; C- Single Pollen structure with germ pore

Table 3: Grain yield, seed yield, vegetative yield, biomass and harvest index (%) of foxtail millet in g plant^{-1} during *kharif* season 2023.

Parameters	Yield (g plant^{-1})	Yield (g m^{-2})	Yield (kg plot^{-1})	Yield (kg ha^{-1})
Grain yield	11.5	155	1.31	1500
Seed yield	10.4	147.66	1.0	1470
Vegetative yield	14.86	491.33	4.15	4910
Biomass	25.26	639	5.58	6390
Harvest index % (grain)	46	24.2	23.47	23.47
Harvest index % (seed)	41.17	23.10	17.92	23

The pollen grain is spherical structure which having inner and outer cell wall, inner wall is called exine while outer wall is known as intine. foxtail millet pollen is yellowish in colour, with a single pore, called germ pore which helps in the formation of pollen tube.

Yield and yield parameters in foxtail millet

At the final harvest grain yield was recorded by sampling the plants as plant^{-1}, m^{-2}, plot^{-1} and expressed results in the similar unit. Grain yield was recorded 11.5 g plant^{-1}, 155 g m^{-2}and 1.31 kg plot^{-1}. Grain yield was calculated in kg ha^{-1} from the plot^{-1} and yield was found 1500 kg ha^{-1}. Seed yield was calculated after purifying the seed physical and morphological basis. This was determined by dipping the seed in tap water and after soaking, seed were setting down and some seed were floating in the water. Settled seed were separated and considered as quality seed. The seed yield was 10.4 g plant^{-1}, 147 g m^{-2}, 1 kg plot^{-1} and seed yield was calculated in kg ha^{-1} from the plot^{-1} and seed yield was found 1470 kg ha^{-1}.

Similarly, vegetative yield was recorded after harvest in sun dried plant for four to five days. It was recorded 14.86 g plant^{-1}, 491.33 g m^{-2}, 4.15 kg plot^{-1} and calculated 4910 kg ha^{-1} from the plot^{-1}. Biomass were calculated from the grain yield and vegetative yield in the sun- dried sample and it was recorded as 25.3 g plant^{-1}, 639 g m^{-2}, 5.58 kg plot^{-1} and calculated 6390 kg ha^{-1}. Harvest index is a relation between yield and biomass. It was separately calculated for grain yield and seed yield. Harvest index for grain was calculated, 46 % for plant^{-1}, 24.2 % for m^{-2}, 23.47 % for plot^{-1} and ha^{-1}, while harvest index of seed was 41.7 % for plant^{-1}, 23.10 % for m^{-2}, 17.92 % for plot^{-1} and 23 % for ha^{-1}.

Seed quality analysis

Seed quality parameters of foxtail millet were evaluated after harvesting, threshing, proper cleaning and seed drying. Test weight was recorded as 3.6 g, including

good seed development and uniformity. The moisture content of seed was 12%, which helps in maintaining seed viability. The seeds exhibited a high germination percentage of 94%, reflecting excellent physiological quality. The speed of germination was 23, suggesting rapid and uniform seedling emergence, Comparable results were also reported by Suvarna *et al.*, (2019).

The root length of seedling was 8.7 cm, while the shoot length was 8.2 cm, including vigorous early seedling growth. Based on germination percentage and seedling length, the Seedling Vigour Index-I (SVI-I) was calculated as 1,627.5 demonstrating high seed vigour. Similarly, the Seedling Vigour Index-II (SVI-II) derived using seedling dry weight, was 0.15, further confirming the good quality of the seed lot. The electrical conductivity of seed leachates was very low (0.08 µS/cm/g), indicating minimal membrane damage and high seed integrity. Overall, the recorded parameters clearly reveal that the foxtail millet seeds possessed and superior physical and physiological quality after post-harvest processing.

Conclusion

The study on foxtail millet variety SIA-3156 demonstrated its good adaptability and stable performance under the agro-climatic conditions of Uttarakhand during the *kharif* season. The foxtail millet variety exhibited rapid and uniform phenological development, with timely flowering and anthesis, indicating synchronized growth behaviour. Yield attributes revealed satisfactory grain and seed yields with a favourable harvest index, indicating efficient partitioning of assimilates towards economic yield. This study confirms that foxtail millet variety SIA-3156 possesses desirable agronomic performance, yield potential and excellent seed quality. Hence, it can be recommended as a promising crop for sustainable cultivation and quality seed production in similar agro-ecological regions.

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