

# PEARL MILLET BIOLOGY

Project Coordinator, AICRP- Pearl millet (ICAR), ARS, Mandor, Jodhpur

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## Origin of pearl millet

Pearl millet originated in tropical Western Africa some 4000 years ago. It is a member of the grass family, originally a wild plant in Africa where largest members of both wild and cultivated forms of this species occur. From there, it differentiated into two races; *globosum* race that moved to the western side and the *typhoides* race that reached Eastern Africa and spread to India and southern Africa some 2000–3000 years ago. The evolution of pearl millet under the pressures of drought and high temperatures imparted the ability to tolerate drought, nutrient deprived soil and high temperatures of Indian and African hot deserts more effectively than other cereals like wheat and rice.

## Taxonomy

*Pennisetum* is largest genera in the tribe *Paniceae* with five sections and approximately 140 species that are widely distributed in the tropics and subtropics (Clayton 1972). It is placed close to the genus *Cenchrus* (Stapf and Hubbards, 1934 and Bor, 1960) on the basis of spikelets that are arranged in groups surrounded by involucre. Inter-generic hybrids between pearl millet and *Cenchrus ciliaris* L have also been reported (Read and Bashaw, 1974). According to Brunken (1977), *Pennisetum* includes two reproductively isolated species viz. *P. purpurium* Schumach, a tetraploid ( $2n = 28$ ) perennial species which occurs throughout the wet tropics of the world; and *P. americanum* (syn. *P. glaucum*) (L) Leeke, a diploid annual species, native to the semi-arid tropics of Africa and India. *P. glaucum* (*P. americanum* according to Brunken 1977) contains three sub species:

- a) Sub-sp *glaucum*- cultivated, involucre persistent at maturity, distinctly stalked
- b) Plants wild or weedy, involucre readily deciduous at maturity, short stalked or sub-sessile.
  - i. Subsp, *violaceum (monodii)* - Involucre sub-sessile, stalks less than 0.25 mm long; mature grains 0.6-1.0 mm deep. Considered to be wild progenitor of cultivated pearl millets.
  - ii. Subsp, *stenostachyum* – Involucre short stalked; stalk more than 0.25 mm long, mature grain 1.0-2.0 mm deep.

*Pennisetum glaucum* ssp *glaucum* is the only cultivated species for seed purpose, *P. purpurium* and its hybrids with bajra in both directions (bajra x napier and napier x bajra) are cultivated for fodder purposes in some areas of world and India.

The taxonomical classification presently adopted for pearl millet is based on Clayton 1972. However, de Wet (1977) accepted *Pennisetum glaucum* for annual pearl millet species instead of *P. americanum* suggested by Brunken (1977), present classification accepted is –

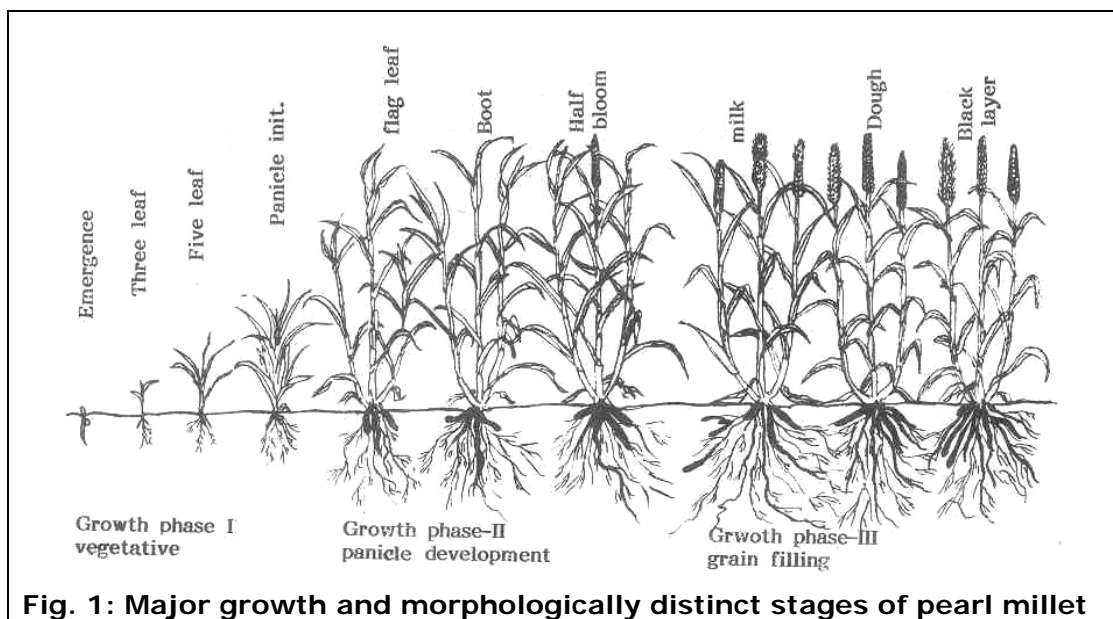
Family	: <i>Poaceae</i>
Subfamily	: <i>Panicoideae</i>
Tribe	: <i>Paniceae</i>
Subtribe	: <i>Panicinae</i>
Section	: <i>Panicillaria</i>
Genus	: <i>Pennisetum</i>
Species	: <i>Glaucum</i>

## Biology

Pearl millet (*Pennisetum glaucum* L.) being a C4 species is endowed with a very high photosynthetic efficiency and ability for dry matter production. It is an important coarse

grain cereal and forage crop of the arid and semi-arid tropics of the Indian subcontinent and several African regions. Pearl millet grows on a wide variety of soils including sandy, light textured soils, and may sustain growth on acidic and very infertile soils. At the same time, wide variations displayed by pearl millet for vegetative, reproductive and physiological features are advantageous in development of cultivars suiting to various climates and cropping systems. A sound knowledge of pearl millet biology is essential to realize the real potential of this crop for varied agro-ecological conditions and to enhance the breeder's ability to develop requirement specific cultivars (Begg, 1965; Khairwal et al. 1990).

Pearl millet biology includes all growth and developmental features from germination to seed formation (Begg, 1965, Maiti and Bisen, 1976, Gregory and Squire, 1979, Maiti, 1979, Fussel et. al., 1980, Powers et. al., 1980, Maiti and Bidinger, 1981, Vanangamudi, 1987, Khairwal et. al., 1990, and Mangat et. al., 1999). These features include three well defined growth phases i.e. vegetative, reproductive and grain filling which shall be discussed in relation to crop improvement (Fig. 1, Table 1).



**Fig. 1: Major growth and morphologically distinct stages of pearl millet**

**Table 1: Three major growth phases and morphologically distinct development stages of pearl millet plant<sup>1</sup>**

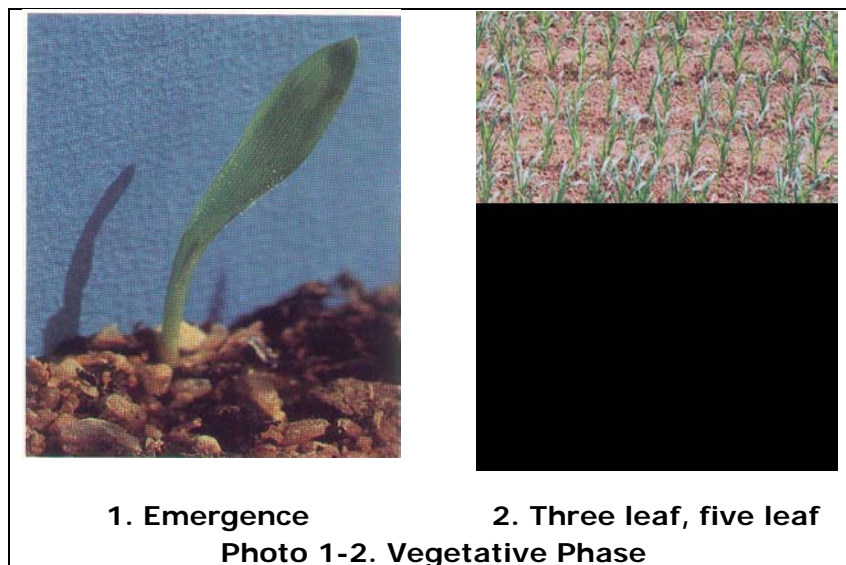
Growth Phases	Identifying characteristics	Approximate days after emergence*
<b>GP I</b>	<b>Vegetative phase</b>	0-21
	Emergence stage	2-3
	Three leaf stage	3-7
	Five leaf stage	7-14
	Panicle initiation stage	14-21
<b>GP II</b>	<b>Reproductive/Panicle development phase</b>	21-42
	Flag leaf stage	21-28
	Boot stage	28-35
	Half bloom stage	35-42
<b>GP III</b>	<b>Grain filling phase</b>	42-77
	Milk stage	42-49
	Dough stage	49-56
	Black layer formation or physiological maturity	56-63

<sup>1</sup> Main shot

\* May vary with environmental conditions, locations and varieties

### Vegetative Phase

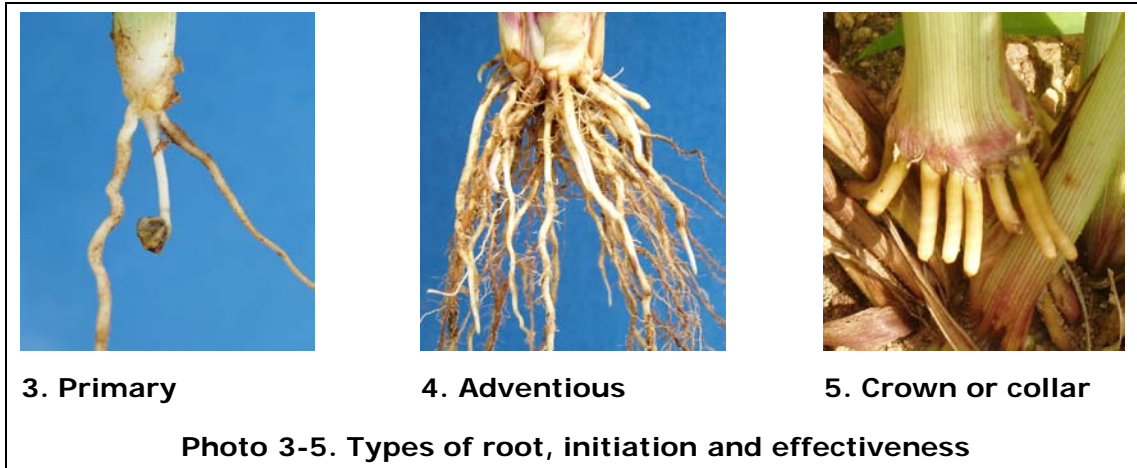
Upon germination radicle starts emerging from the hilar region approximately within 16 hours of the initiation of the germination followed by development of plumule and coleoptile sheath approximately two hours later. Radicle grows downwards rapidly and produces fine root hairs. Coleoptile grows upwards slowly through soil until it emerges from the soil surface. Emergence of coleoptile from soil surface depends upon the depth of sowing, soil texture, moisture and temperature. It takes 2-3 days under favorable conditions (Photo 1-2).



Pearl millet has a typical monocotyledonous type of root system consisting of seminal or primary root, adventitious roots, and crown or collar roots (Table 2, Photo 3-5).

**Table 2: Types of root, initiation and effectiveness**

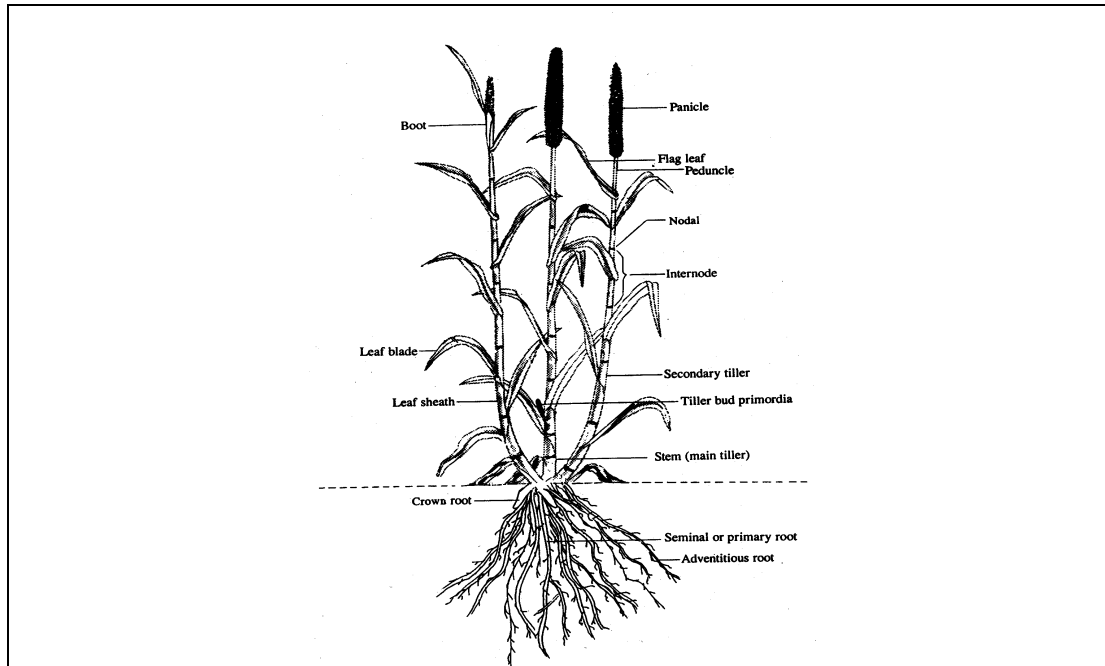
Types	Initiation time	Effective up to
Primary	within 4 days	45-60 days
Adventitious	8-12 days	Maturity
Crown or collar	30-40 days	Maturity



**Photo 3-5. Types of root, initiation and effectiveness**

Pearl millet root can penetrate up to 180 cm and attain a total length of 1500 m per m<sup>2</sup> of the cultivated area and touch 3000 m per m<sup>2</sup> at the harvest with a mass of 35 g per m<sup>2</sup>. In sandy soils, a mature pearl millet plant can spread its roots to about 3 m to absorb water. In heavily tillering plants, roots have more horizontal spread than deep penetration. It has been observed that genotypes tolerant to early season drought (3-15 days after sowing) have 30 % more root length than the susceptible one.

Pearl millet is an erect annual with a good tillering habit (Fig. 2). The main stem attains a height of 2 - 4 m with 0.5 - 1.5 cm diameter. It is generally round to oval in shape. Nodes are slightly swollen, may be pubescent with ring of adventitious root primordia at the basal end and its inter-nodes are glabrous. The internodal length increases from the base of the stem upwards. Single leaf appears on each node in alternate orientation. An axillary bud is borne on the node at the base of the groove, which may remain dormant or develop in to a nodal tiller. Soft and thin palatable stem having very low fiber content is desirable for forage. Dry matter accumulation is increased in stem in the long duration pearl millet which limit the increase in grain yield in such types. Genotypic variation exists for stem growth, thickness, internode length and colour (Photo 6-8).

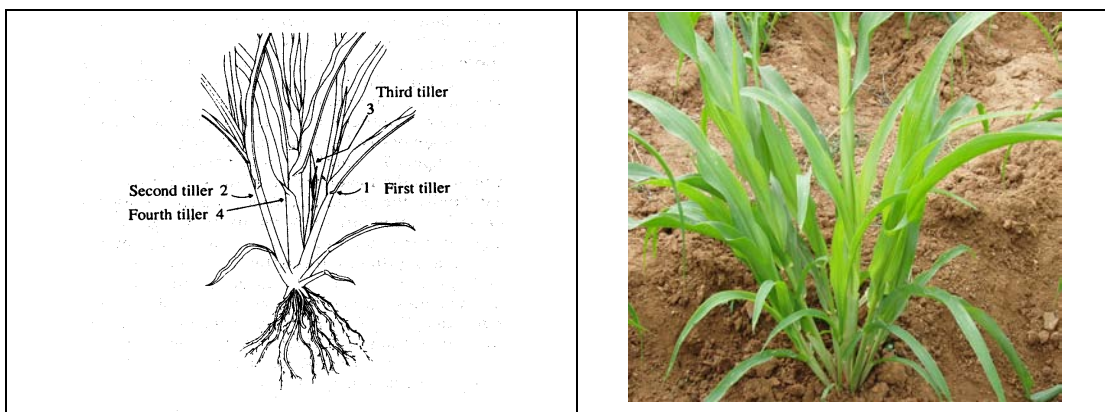


**Fig. 2. The pearl millet plant**



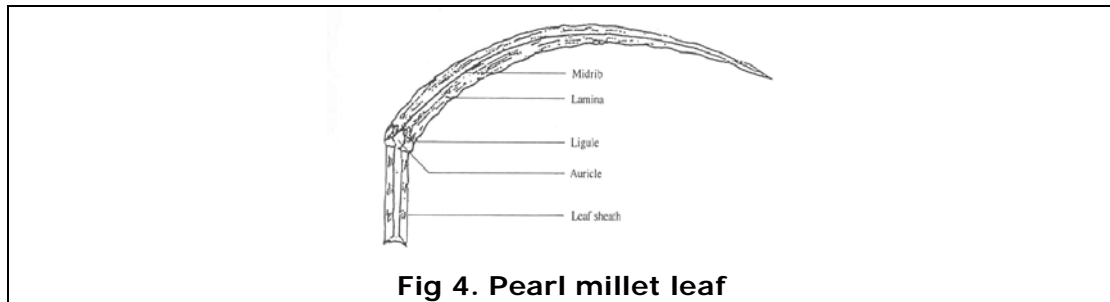
**Photo 6-8. Genotypic variation for stem colour**

The tiller leaf appears ~ 12 days after seedling emergence from the base of the main stem on both sides, following the alternate arrangement of leaves (Fig. 3). Pearl millet has the potential to produce many effective tillers that may increase under wide spacing. Synchrony in flowering coupled with a higher number of effective tillers enhances the probability of producing more seeds from the same plant.



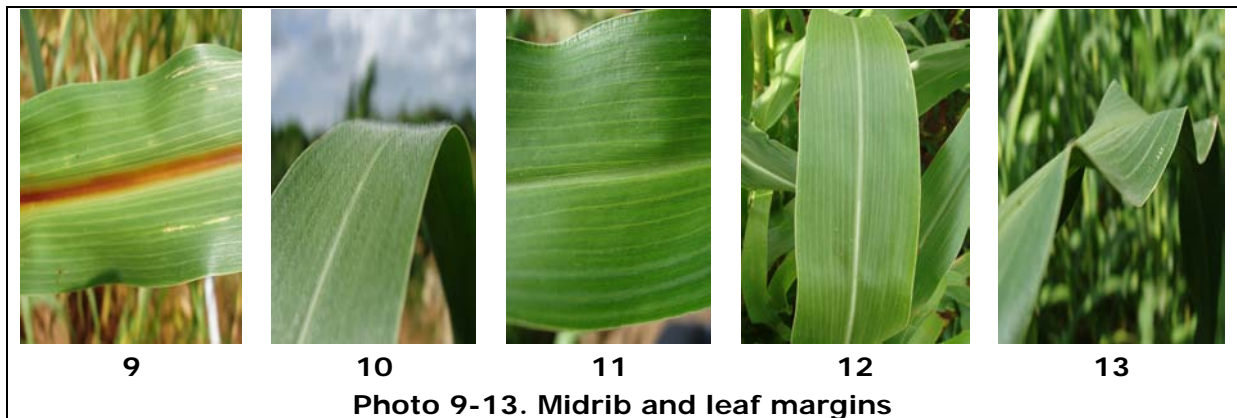
**Fig. 3: Development of tillers in pearl millet**

Leaves are linear, 20-100 cm long and 0.5-5.0 cm wide, usually sparse to densely hairy or glabrous. The leaf consists of a leaf sheath and lamina or blade (Fig. 4).



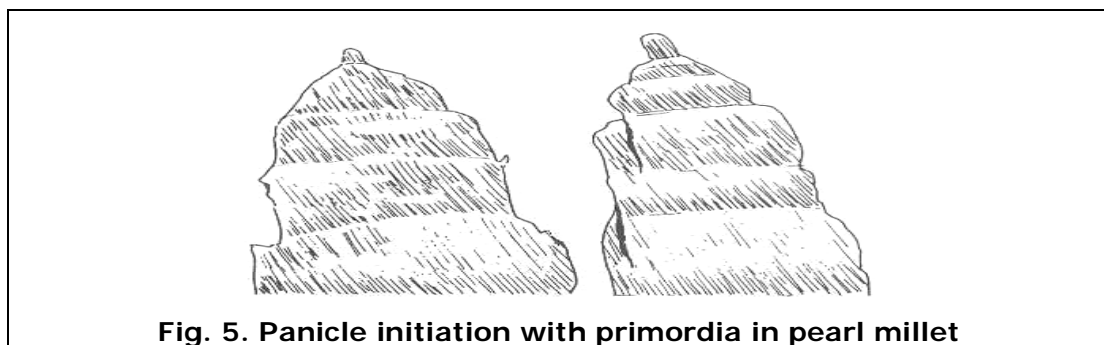
**Fig 4. Pearl millet leaf**

The midrib may or may not be prominent. The leaf margins bear small saw teeth (see photo 9–13). Stomata are present on both leaf surfaces in equal numbers, varying approximately 45-96 stomata per mm<sup>2</sup>. Early maturing genotypes have less number of leaves with faster growth and emergence that helps to escape early drought. The Kranz anatomy, a characteristic of C<sub>4</sub> pathway in pearl millet makes it adaptive to drought and palatable for grazing cattle.



### Reproductive Phase

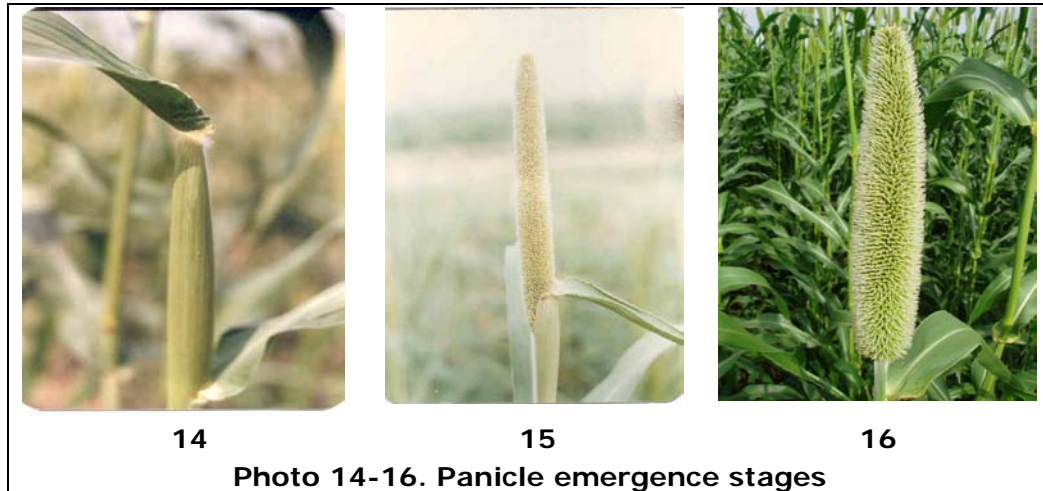
A change from vegetative to reproductive phase is marked by the formation of an apical dome - like structure and a constriction at the base of the shoot meristem (Fig. 5) leading to a change from leaf primordia to spikelet primordia, development of spikelets, florets, glumes, stigmas and anthers. The period between panicle initiation to anthesis is critical in determining the grain number.



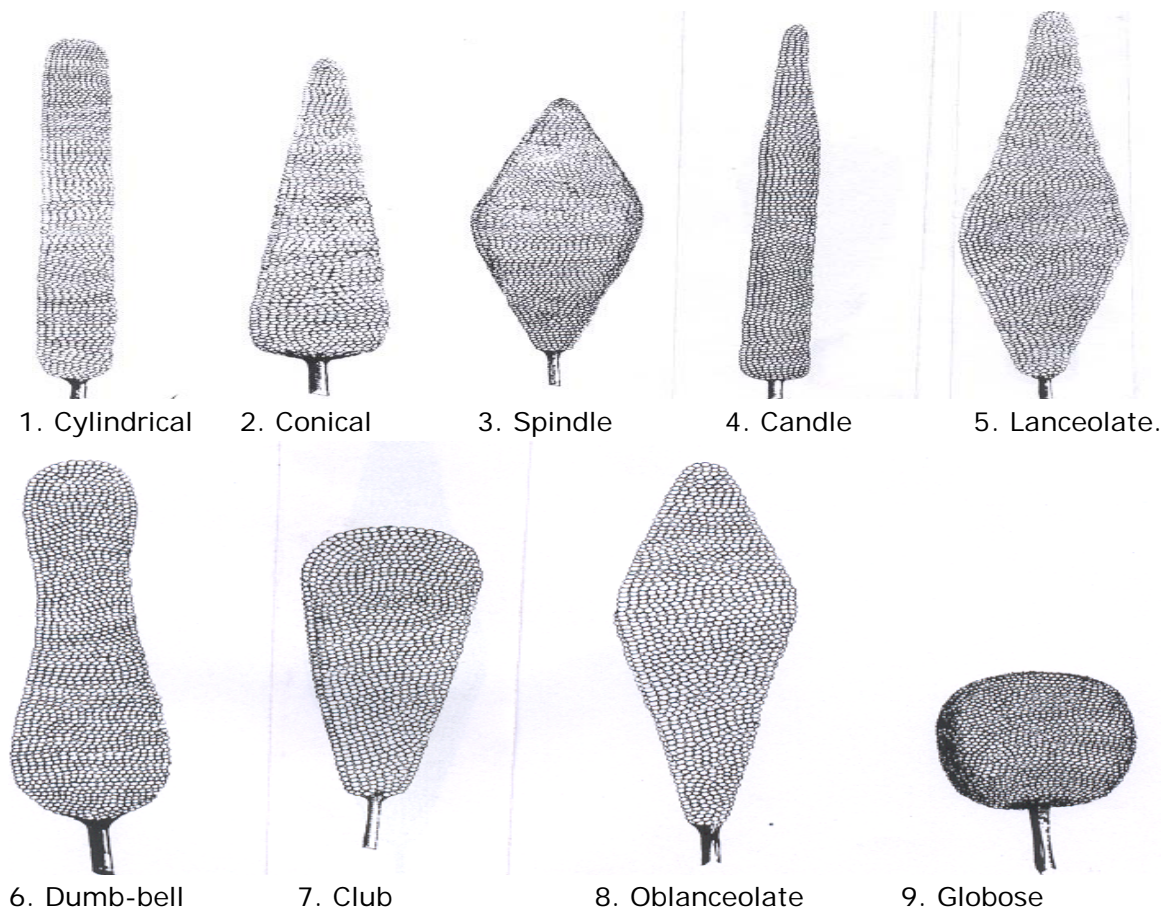
**Fig. 5. Panicle initiation with primordia in pearl millet**

Panicle emerges in ~35-70 days from the day of sowing depending upon the early or late genotypes. Panicle emergence is marked by the rapid elongation of the peduncle and the inter-node below it, and by the appearance of the flag leaf or boot leaf (Photo 14). Panicle takes nearly six days to emerge from the leaf sheath (Photo 15), with the

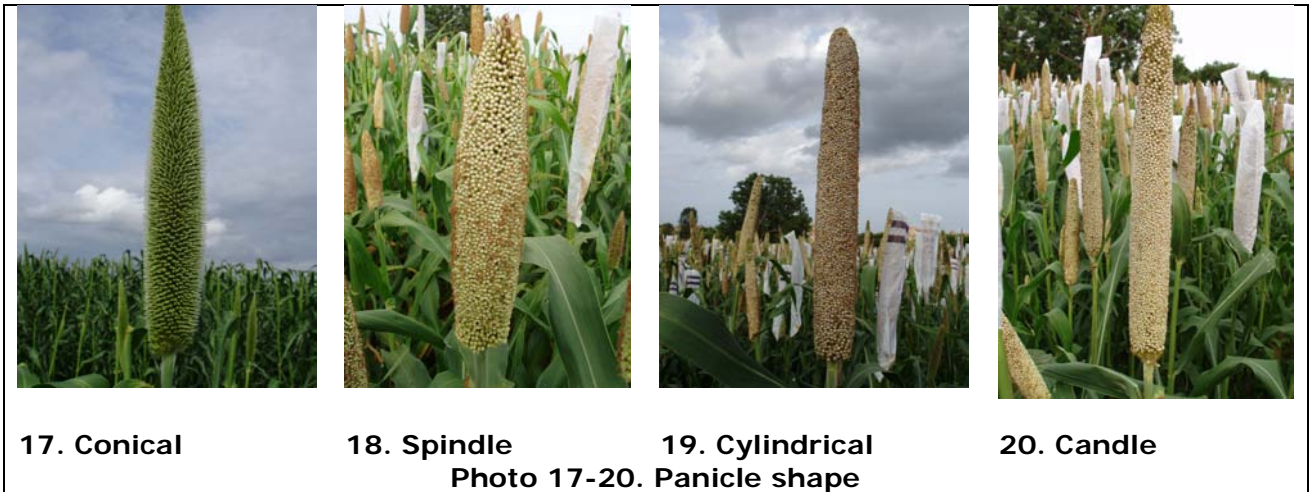
maximum emergence on the fourth or fifth day (Photo 16). Hybrids generally take less time for panicle emergence than their parents indicating heterosis for the early panicle emergence.



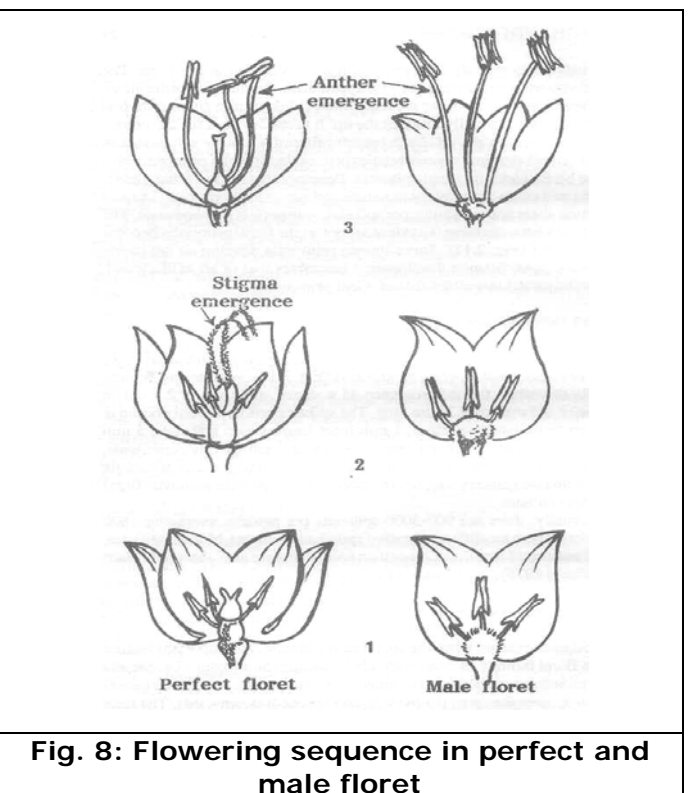
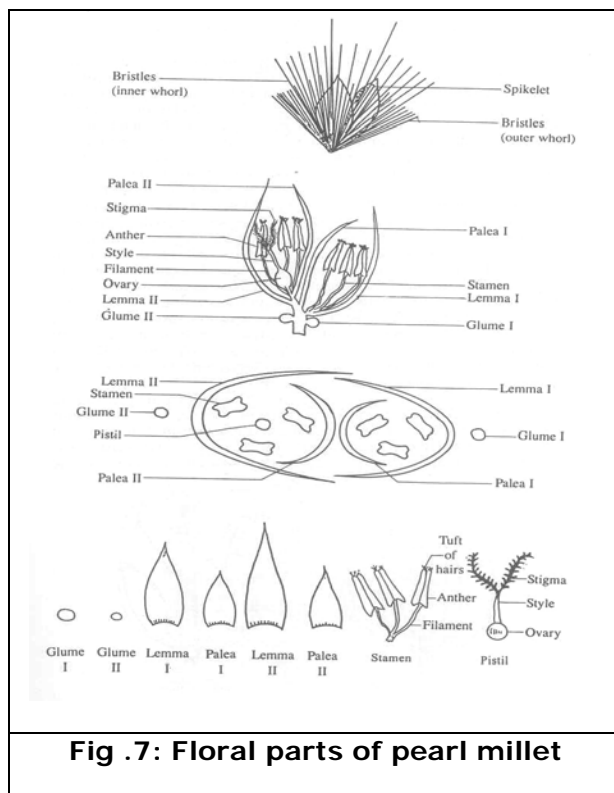
Pearl millet inflorescence is a compound terminal spike called panicle and its length generally varies between 20-25 cm with a circumference of 7-9 cm (see photo 16). The panicle shape varies considerably as shown in Fig. 6, but, the common shapes are either cylindrical or conical.



**Fig. 6: Panicle shapes**



Inflorescence consists of a central rachis covered with soft/short hairs and bears fascicles on rachillae. The density of fascicles and the length of rachillae determine the degree of compaction of the panicle. Each fascicle contains spikelets surrounded by a wall of bristles (i.e., involucre) (Fig. 7). The prolongation of the fascicle axis determines the length of bristles (Photo 21).





- Fascicles
- Spikelets 800-3000 (1600)
- One spikelet – 2 glumes



**Photo 21. Bristles in the panicle**

A spikelet may contain 2-4 flowers or florets, but generally two. The lower floret is staminate and the upper floret is bisexual or hermaphrodite (Fig. 7, Photo 22-23, Fig. 8).



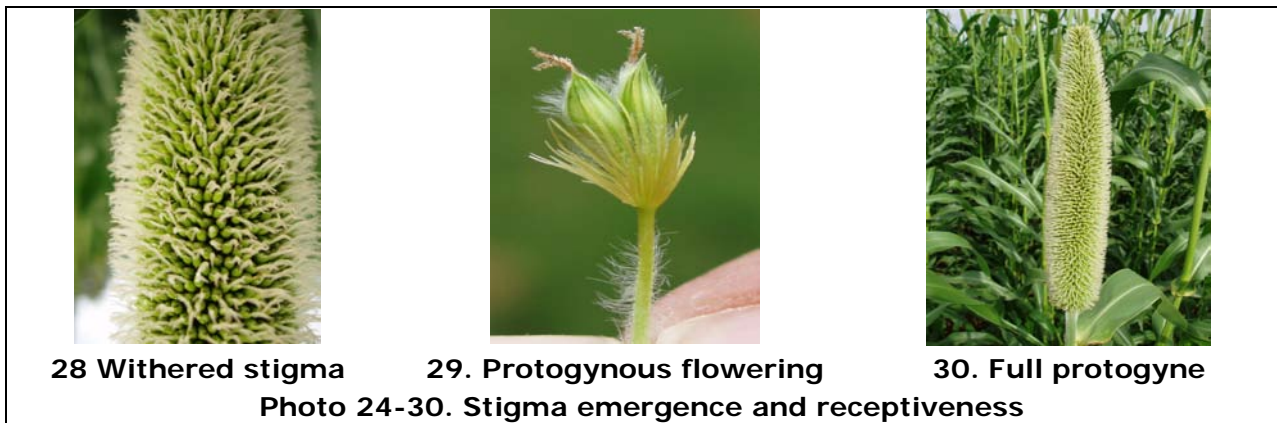
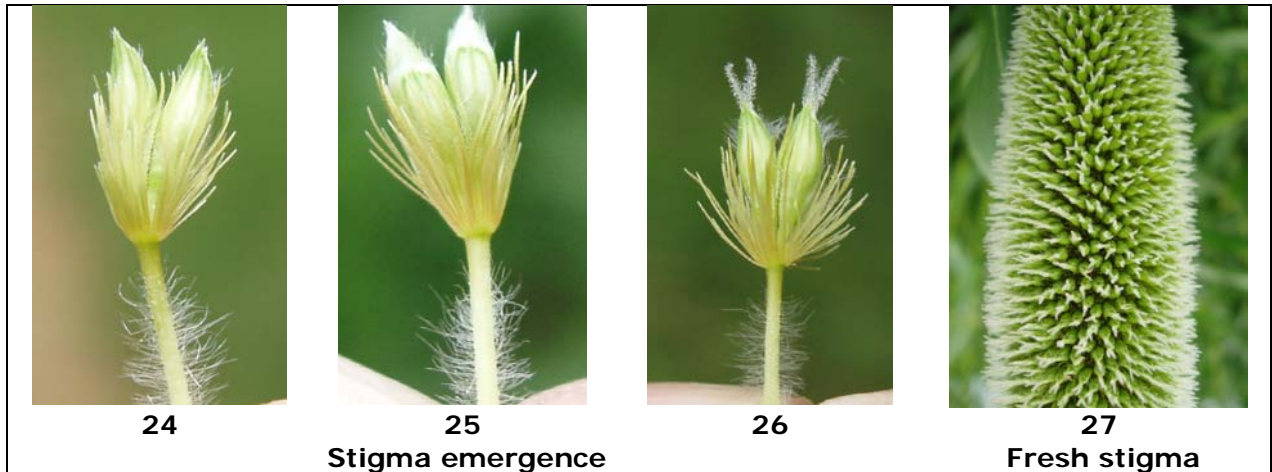
**22. Staminate**



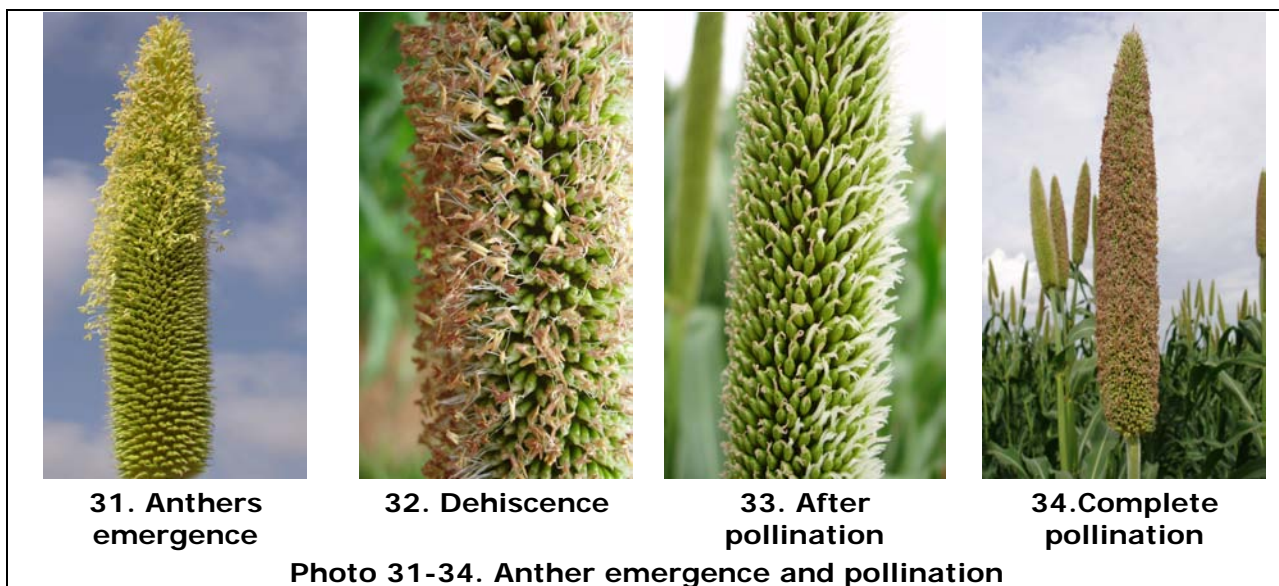
**23. Hermaphrodite**

**Photo 22-23. Staminate and hermaphrodite flowers**

Pearl millet is a protogynous species. The styles start protruding two to three days after the emergence of the panicle. The stylar branches protrude first from the florets in the upper middle region of the panicle and then proceed both up and downwards. In the hermaphrodite flowers, the stigmas emerge earlier than the anthers and hence stigmas receive pollen from inflorescence of other plants. The time required for complete stigma emergence varies from 2 to 3 days and they remain receptive for next two to three days (Photo 24-30).



By the time anther emergence commences, the stigma would have emerged and also pollinated, avoiding selfing. The emergence of the first anther usually begins about three to four days after the first stigma has emerged. The anther emergence occurs in two phases. The first phase involves solely the hermaphrodite flowers, and the second phase includes the staminate flowers. When the first phase of the emergence of anthers has reached the basal spikelets, the second phase begins when the staminate flowers are functional from the upper part of the panicle (Photo 31-34). A panicle continues shedding pollen for about 3 days. The anther emergence continues throughout the day and night. The anthesis occurs between 8 am and 2 pm with a peak at about 10 am. The increase in humidity and a decrease in temperature have been noted to reduce anther emergence, while lowering of humidity and a rise in temperature enhances up the anthesis.



Pearl millet is a highly cross-pollinated species. Wind is supposed to be the major cross pollinating agent. However, insects also effect cross pollination. Protogyny and the time lag between stigma emergence and anther dehiscence favor cross pollination, but asynchronous flowering prevents its full realization. The protogyny in pearl millet is exploited for controlled cross pollination without resorting to emasculation.

#### **Selfing and Crossing Techniques**

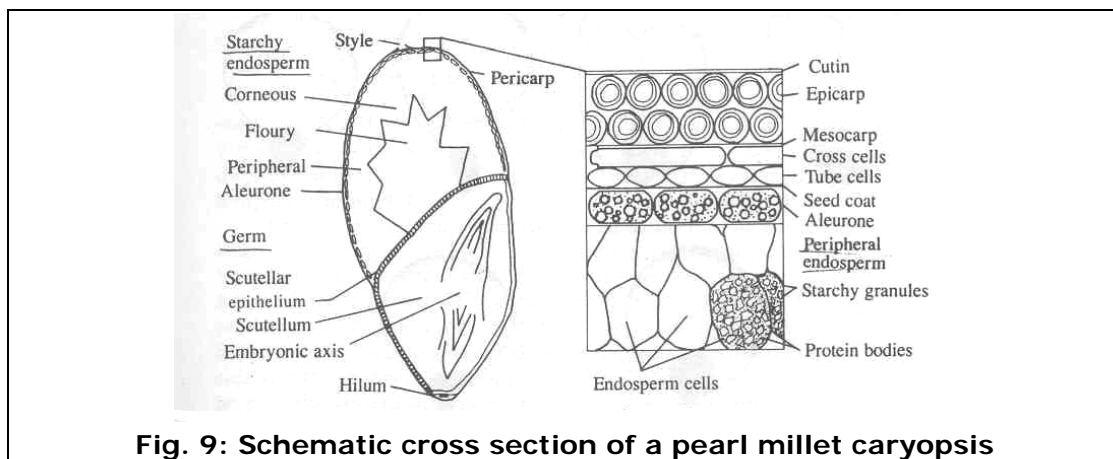
Controlled pollination without resorting to emasculation is a common phenomenon in pearl millet. Usually, there are 900-3000 spikelets per panicle, averaging 1600 spikelets. Each spikelet has two florets, one bisexual and the other, staminate. The bisexual or hermaphrodite floret consists of a pistil and three anthers while the staminate floret has three anthers. Looking to tender, large number and small structure of florets, it is difficult to follow emasculation in pearl millet. Protogynous nature is exploited for effecting cross-pollination; protogyny, is a unique feature in which the stigmas emerge and become active earlier than anthers or pollen dehiscence and receive pollens from other plants. This sequence of flowering practically excludes self pollination in the same inflorescence.

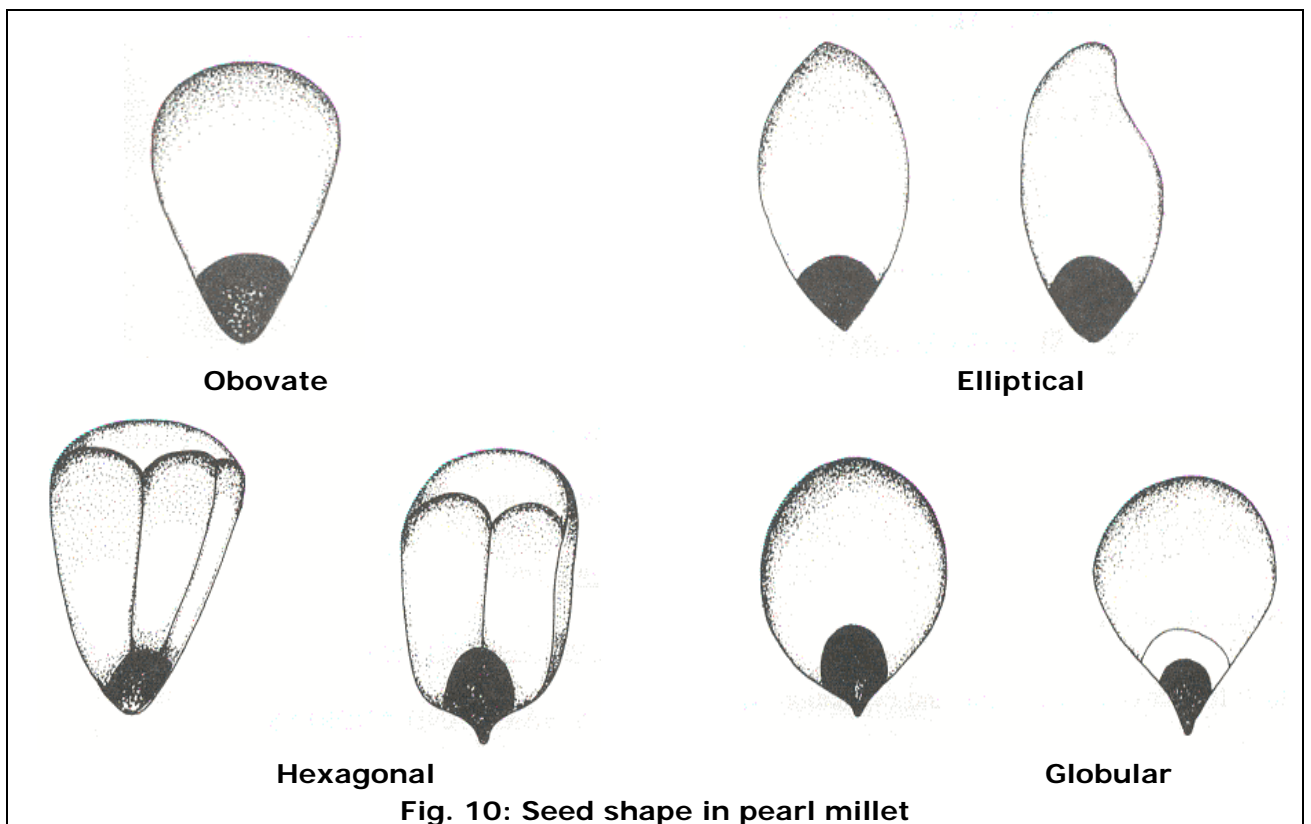
The inflorescence to be used as a female or male is covered with the glassine paper bag before any stigma is visible. Generally, the safest stage is when about one third of the inflorescence is out of the flag leaf sheath. When all stigmas have emerged, the panicle can be considered ready for cross pollination. If selfed seed of the male parent is not required, fresh pollen from dehiscing anthers, visible as yellow powder in the transparent selfing bags can be collected by tapping even in the inflorescences in which stigmas have completely emerged. The pollination is carried out by quickly removing the bag from the female inflorescence, dusting the pollen collected from the male inflorescence, and then rebagging the pollinated inflorescence (see photo 35-36).



**Grain filling stage:**

Pearl millet seed is a caryopsis (Fig. 9 photo 37-42) and its shape is highly variable, ranging from globular to conical shape (Fig. 10). The seed colour varies from ivory to purplish black, with light to deep gray being the most common seed colour. A small embryo is present on the depressed or flat surface at the tapering end of the seed. The size of the grain depends on its position in the panicle, being largest at the base, medium in the middle, and smallest at the apex. Variations exist in grain size among varieties generally ranging from 4-12 g per 1000 grains.





Seed viability and seedling vigor are dependent upon the extent of grain development. Selection of varieties with higher percentage of seed filling and larger seed size may lead to higher yields. The temperature at which the seed developed did not affect seed viability, but it did affect the vigour. Post-harvest dormancy has been reported for at least 14 days in pearl millet (Burton, 1969; Khairwal, 1980; Khairwal et al., 1980). However, pearl millet grains germinated in the inflorescence when harvesting was delayed in prolonged wet weather.

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