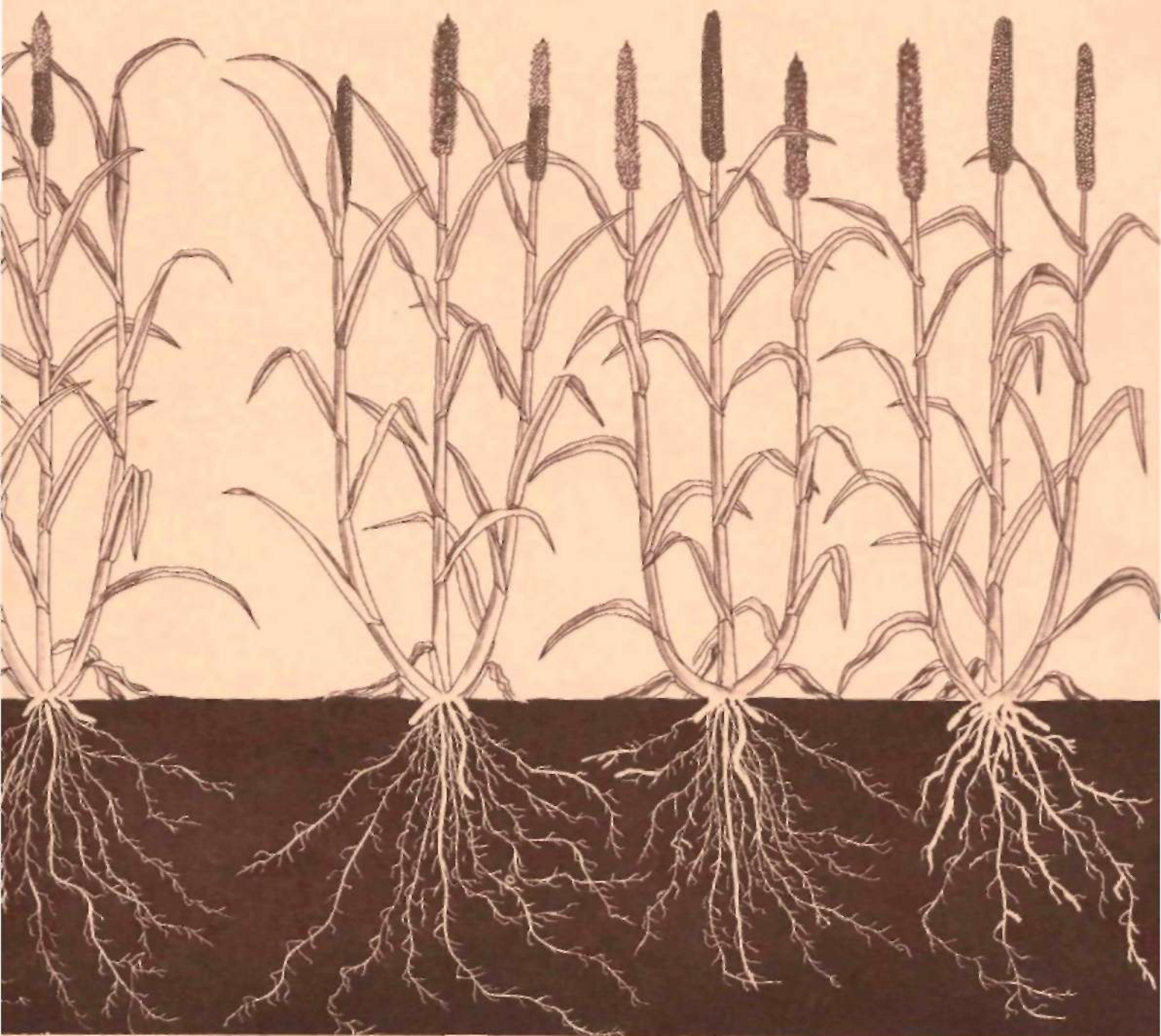


Growth and Development of the Pearl Millet Plant



Research Bulletin No. 6

International Crops Research Institute for the Semi-Arid Tropics

Abstract

Maiti, R.K., and Bidinger, F.R. 1981. *Growth and development of the pearl millet plant*. Research Bulletin no.6. Patancheru, A.P., India: International Crops Research Institute for the Semi-Arid Tropics.

Pearl millet (*Pennisetum americanum* [L.] Leeke) is one of the most important food crops in the drier semi-arid tropics. The bulletin describes its three major growth phases: the vegetative phase, from emergence to panicle initiation of the main stem; the panicle development phase, from panicle initiation to flowering in the main stem; and the grain-filling phase, from flowering to physiological maturity. Each phase has been subdivided to make a total of nine morphologically distinct and recognizable growth stages. Descriptions and characteristics to identify each of these stages are supported with 21 illustrations, some of them in color. The bulletin also describes the growth and development of the major plant parts: root, tiller, leaf, stem, panicle, and grain. The data given are derived from several years of research on the physiology of the crop, and the publication should thus serve not only as a source of basic information on the growth and development of pearl millet, but as a reference for comparing millet with other cereal crops based on a standard system for recording the developmental stages of the crop.

Résumé

Maiti, R.K., and Bidinger, F.R. 1981. Growth and development of the pearl millet plant. (*Développement du mil à chandelle*.) Research Bulletin No.6. Patancheru, A.P., India: International Crops Research Institute for the Semi-Arid Tropics.

Le mil à chandelle (*Pennisetum americanum* [L.] Leeke) est l'une des plus importantes cultures vivrières des parties les plus sèches des zones tropicales semi-arides. Ce bulletin décrit ses trois phases de croissance principales: la phase végétative, allant de l'émergence à la formation de la panicule sur la tige principale; la phase du développement de la panicule, allant de sa formation à la floraison sur la tige principale; la phase du remplissage des grains allant de la floraison à la maturité physiologique. Chacune de ces phases a été subdivisée et l'on retrouve en tout neuf stades de développement morphologiquement distincts et identifiables. Vingt-et-une illustrations, dont quelques-unes en couleurs, accompagnent les descriptions et les caractéristiques de chacun de ces stades et en facilite l'identification. Ce bulletin décrit aussi le développement des principales parties de la plante: racine, talle, feuille, tige, panicule et graine. Plusieurs années de recherches sur la physiologie de cette plante ont fourni les données de ce bulletin. Il peut servir à la fois comme source d'information de base sur le développement du mil à chandelle et permettre de comparer cette plante à d'autres cultures céréalières en utilisant un système uniforme pour enregistrer les stades de développement.

Growth and Development of the Pearl Millet Plant

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Introduction

In the drier semi-arid tropics of the world, pearl millet (*Pennisetum americanum* [L.] Leeke = *Pennisetum typhoides* Stapf. and Hubbard) is one of the most important crops of the small farmer. It is particularly adapted to conditions of nutrient-poor soils and low rainfall, yet is capable of rapid and vigorous growth under favorable conditions. It is grown both as a grain and a forage crop and is the major cereal for the people in the drier areas of the Indian subcontinent and of both West and East Africa. Yet until very recent times, pearl millet received comparatively little attention from the scientific community.

This research bulletin provides a description of the general growth and development of pearl millet based on three major growth phases, followed by a more detailed description of a series of nine stages into which the growth cycle can be divided for easy reference and description. A detailed account of the development of each of the major plant parts, based on information developed at ICRISAT, is presented in the concluding section.

The information in this bulletin should find several uses: as a source of basic knowledge of the

growth and development of pearl millet for students and trainees, as a reference for comparing pearl millet with other cereal crops for scientists and teachers, and as a standard system of recording the developmental stages of the crop for agronomists, plant protection scientists, and others working with this crop.

General Outline of Crop Growth (Growth Phases)

The growth cycle of pearl millet may be divided into three major developmental phases: the vegetative phase (GS₁)—from emergence to panicle (floral) initiation of the main stem; the panicle development phase (GS₂)—from panicle initiation to flowering of the main stem; and the grain-filling phase (GS₃)—from flowering to the end of the grain-filling period (physiological maturity) of the crop (Fig. 1).

GS₁ : Vegetative phase

This phase starts with the emergence of the seedlings and continues up to the point of panicle initiation. During this phase, the seedlings establish their primary root system (seminal roots) and

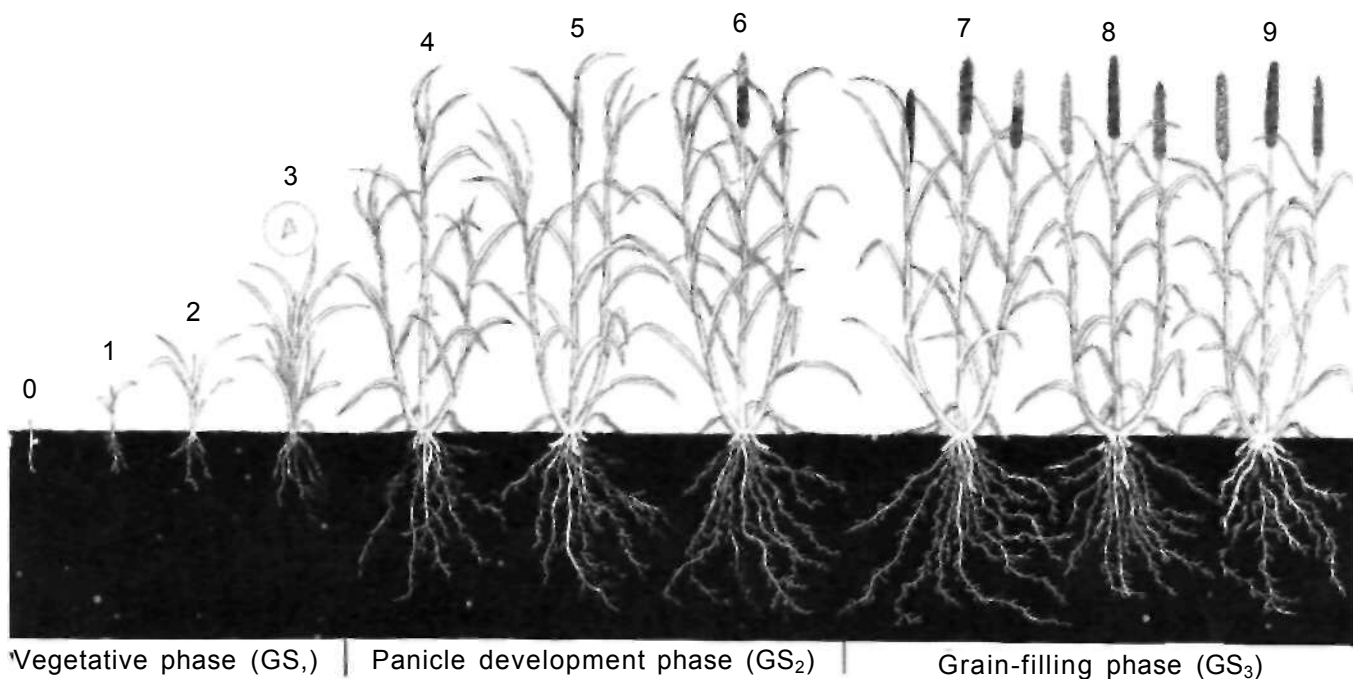


Figure 1. Schematic diagram of the major growth phases of pearl millet: GS₁, GS₂, GS₃. The numbers 0 to 9 illustrate the detailed stages of growth listed in Table 1, and described on pp. 2-6. The encircled enlargement of stage 3 shows the dome-like shape of the apex, and the constriction at its base, that may be observed at this stage of change from the vegetative to the reproductive phase.

produce adventitious roots. All leaves are initiated during GS₁ and, in early varieties, six or seven leaves (including the embryonic leaves) are fully expanded by the end of this phase. Tiller buds are formed, their leaf primordia initiated, and several tillers emerge by the end of the phase. There is little internode elongation, however, and the apical meristem remains at or below the soil surface. Dry-matter accumulation is almost entirely confined to leaves and roots.

Floral or panicle initiation is marked by the elongation of the apical dome and the formation of a constriction at the base of the apex (Fig. 4). The size of the apex at floral initiation ranges from as little as 0.5 mm in early varieties to as much as 1.0 mm in late varieties in which floral initiation may not occur until 50-80 days after sowing.

GS₂: Panicle development phase

During this phase all the remaining leaves expand fully and the earliest expanded leaves at the base of the stem begin to senesce. Stem elongation occurs by sequential elongation of internodes beginning at the base of the stem. Tillers emerge, undergo floral initiation, leaf expansion, etc., in patterns similar to that of the main stem. The first-formed tillers follow the main stem closely in their development, whereas the development of the late tillers frequently ceases due to competition and/or suppression by the more advanced main stem and early tillers. Dry-matter accumulation takes place in roots, leaves, and stem.

During stem elongation the panicle undergoes a series of distinct morphological and developmental changes, described below. These include the development of spikelets, florets, glumes, stigmas, anthers, and finally stigma emergence (flowering) and pollination, which marks the end of the GS₂ phase.

GS₃: Grain-filling phase

This phase begins with the fertilization of florets in the panicle of the main shoot and continues to maturity of the plant (main stem and tillers). Increases in total plant dry weight during this period are largely in the grain but, as tillers in many varieties elongate and flower after the main shoot, there is also some increase in nongrain components, mainly tiller stems.

Senescence of the lower leaves continues and, by the end of the grain-filling phase, normally only the upper two to four leaves remain green. Some varieties develop small tillers in the upper nodes of the stem, particularly towards the end of the

grain-filling phase. These tillers have a shorter developmental cycle than the basal tillers, producing only a few leaves and a small panicle.

The end of the grain-filling phase (physiological maturity) is marked by the development of a small dark layer of tissue in the hilar region of the grain (Fig. 9). This occurs in an individual panicle about 20-25 days after flowering. The grain-filling period for the entire plant (i.e., from flowering of the main shoot to the end of grain filling of the tillers) is longer where tillers flower after the main panicle.

Detailed Stages of Growth

Introduction

The following detailed description of the growth stages of a pearl millet plant divides the life span of the plant into nine morphologically distinct stages following Vanderlip.' The stages and the characteristics to identify them are presented in Table 1. The descriptions refer to the development of the main shoot only, which is used to identify the

Table 1. Developmental timetable by growth stage of The main culm in HB-3 and Mil Zongo, and duration of major growth phases

Growth Stage	Identifying characteristic	Approximate days after emergence	
		HB-3	Mil Zongo,
0.	Coleoptile visible soil surface	0	0
1.	Third leaf visible	6	6
2.	Fifth leaf visible	14	15
3.	Panicle initiation	22	28
4.	Final or flag leaf visible	33	43
5.	Panicle extended in flag leaf sheath	36	47
6.	50% stigma emergence	40	53
7.	Milk stage	49	61
8.	Dough stage	58	69
9.	Black layer formation	65	75

Major growth phase	Approximate duration [days]	
	HB-3	Mil Zongo
GS ₁	22	28
GS ₂	18	25
GS ₃	25	22

VANDERLIP. R.L. 1972 How a sorghum plant develops. Kansas State University Cooperative Experimental Services Report C-447.

stage of development of the plant. The description and illustrations relate to HB-3 (a commercial hybrid of the All India Coordinated Millet Improvement Program) and to an early flowering selection from Mil Zongo (a West African landrace).

Developmental rates are a function of the environmental conditions in which the plant is grown as well as the variety grown. Day length, for example, greatly affects the time to panicle initiation in many varieties, and temperature affects rates of leaf emergence, length of the grain-filling period, etc. The number of days for the attainment of the various growth stages indicated in Table 1 are the averages for environmental conditions during June-September at Hyderabad, India (17°N latitude). Durations of growth stages may vary considerably for other locations and other varieties, particularly for West African landraces which typically do not reach panicle initiation in their West African environments until 50-80 days from emergence. These varieties thus flower in 80-120 days after emergence rather than in 40-50 days as Indian varieties do. As a consequence, the West African types produce many more leaves, stem internodes, and much more total dry weight than do the Indian varieties.

Stage 0: Emergence

This stage begins with the emergence of the coleoptile from the soil surface. Before this occurs, a number of changes have taken place underground. Germination begins with the uptake of water by the seed, which activates metabolism in the cells. Within approximately 16 hours after the initiation of germination, the radicle emerges from near the hilar region, followed by the plumule with the coleoptile sheath approximately 2 hours later. The radicle grows downwards rapidly and produces fine root hairs (Fig. 2). The coleoptile grows upwards slowly through the soil until it emerges from the soil surface. The time required from germination to emergence depends on the depth of planting, soil moisture, and temperature; under favorable conditions it takes 2-3 days.

Stage 1 : Three-leaf stage

Approximately 5 days after emergence of the coleoptile, the lamina of the third leaf can just be seen in the whorl of the second leaf without separating the first and second leaves. The first leaf is fully expanded and the second leaf is still slightly rolled at the base. At this stage the seminal root grows rapidly and develops fine branches. One or

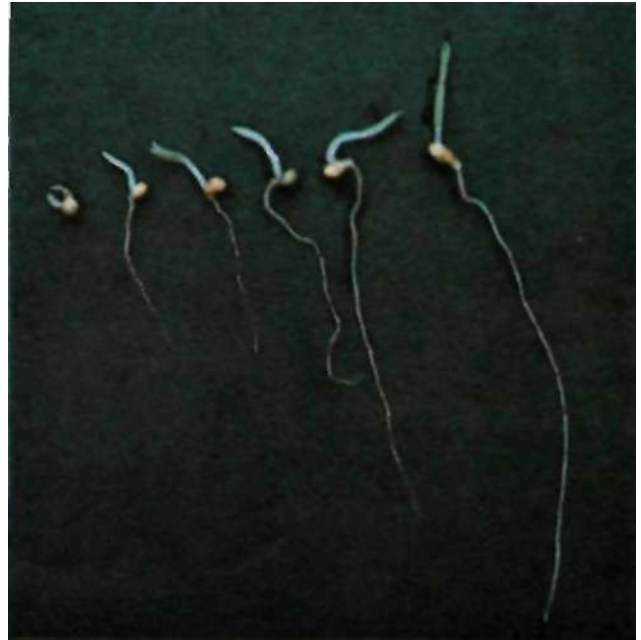


Figure 2. Growth stage 0: Germination and emergence of the seedling.

two adventitious root initials are visible. The leaves are small in size and light green in color (Fig. 3).

Stage 2 : Five-leaf stage

About 13-15 days after emergence the lamina of the fifth leaf is visible. The first and second leaves are fully expanded. The third leaf is still slightly rolled (Fig. 3). The growing point remains below ground level, surrounded by the developing leaf primordia. The seminal root is now well developed and has a number of branches. Adventitious roots start appearing (Fig. 3). Tiller leaves may be seen emerging from inside the sheaths of the basal leaves at this stage. The plant now appears dark green and more sturdy.

Stage 3 ; Panicle initiation (growing point differentiation)

At this stage the growing point changes from the vegetative to the reproductive stage, that is, from the development of leaf primordia to the development of spikelet primordia. This change can be recognized by the fact that the apex becomes dome-like and a constriction develops at its base (Fig. 4).

All leaves have been initiated at this stage; six to seven leaves are fully expanded in early varieties and the remaining are in various stages of



Figure 3. Growth stages 1 and 2: Three-leaf stage (left) and Five-leave stage (right). In both cases the tip of the lamina of the new leaf is just visible in the whorl of previous leaves.

development. Following initiation, the growing point is above the soil surface as the first two or three internodes begin to elongate. The seminal root has produced a network of lateral roots and the adventitious roots are growing rapidly. A number of tillers have now emerged and are undergoing the same developmental pattern as that of the main shoot, although the main shoot is more advanced than the tillers.

Stage 4 : Flag leaf stage

The lamina of the final leaf is visible in the rolled lamina of the preceding leaf. The final leaf is easily distinguished from the preceding leaves as there are no other leaves within the rolled lamina of this leaf as it emerges from the whorl (Fig. 5). Between panicle initiation and the appearance of the flag leaf,



Figure 4. Growth stage 3 : Panicle initiation. The primordium on the left has just reached initiation; the one on the right is approximately 2 days past initiation.

Figure 5. Growth stage 4 : Flag leaf emergence. The tip of the flag leaf lamina is visible in the whorl of the second leaf.



there are numerous changes which occur in the plant. The unexpanded leaves that were present as initials at the time of panicle initiation, sequentially develop, emerge from the whorl, and expand to full size. The stem internodes elongate in sequence, beginning from the base, with each successive internode longer than the previous one. Branch, spikelet and floret primordia are initiated in sequence, the process beginning at the base of the panicle meristem and proceeding towards the top. By the flag leaf stage, the florets are undergoing rapid development. The panicle is enclosed by the sheaths of the flag and penultimate leaves, and is raised well above the soil surface by the elongation of the lower internodes.

Stage 5 : Boot stage

The panicle at this stage is enclosed within the sheath of the flag leaf but has not yet emerged from the collar (Fig. 6). Panicle development is nearing

completion. The panicle rapidly increases in length and width.

Following the boot stage, the panicle emerges from the collar of the flag leaf as the peduncle (the uppermost internode) begins to elongate.

Stage 6 : 50% flowering (half bloom)

Pearl millet is protogynous, i.e., the stigmas appear first. The stigmas begin emerging about 3-5 days after panicle emergence, though this varies with genotype. Stigma emergence starts generally in the florets several centimeters below the tip of the panicle and then proceeds upwards and downwards simultaneously. 50% flowering is attained by the time the stigmas emerge in the middle region of the panicle (Fig. 7). It takes 2-3 days for the completion of stigma emergence, and unpollinated stigmas may remain fresh for several days. However, on pollination stigmas shrivel within a few hours.

On completion of stigma emergence, or in some

Figure 6. Growth stage 5 : Boot stage. The panicle is enclosed in the sheath of the flag leaf.



Figure 7. Growth stage 6 :50% stigma emergence (left) and 50% anther emergence (right).



cases slightly before completion, the emergence of the first flush of anthers begins from near the top of the panicle and proceeds toward the base of the panicle. The process takes 2-3 days for completion (Fig. 7). Anthers emerge in two flushes—the first flush occurs in perfect flowers and the second from the male flowers; thus anther emergence from one head may extend over 5-6 days. Depending on the rate of tiller development, different heads on a plant may flower at the same time, or sequentially.

Stage 7 : Milk stage

Within 6-7 days after fertilization the grains grow sufficiently to become visible within the floret. At this stage they consist of the seed coat filled with first a watery and later a milky liquid. This marks the beginning of the period of rapid starch deposition in the endosperm cells, and the period of rapid increase in the dry weight of the grains (Fig. 8).

Figure 8. Growth stages 7 and 8 : Milk stage (left) and dough stage (right).



Stage 8 : Dough stage

This stage is identified by the change in the endosperm from the mainly liquid milk stage to a first semisolid and then a solid state. It is a gradual change and not a distinct stage, occurring as starch content in the endosperm increases and the moisture percentage declines. Within the dough stage itself there is a gradual change from a soft to a hard dough consistency as grain filling approaches completion (Fig. 8).

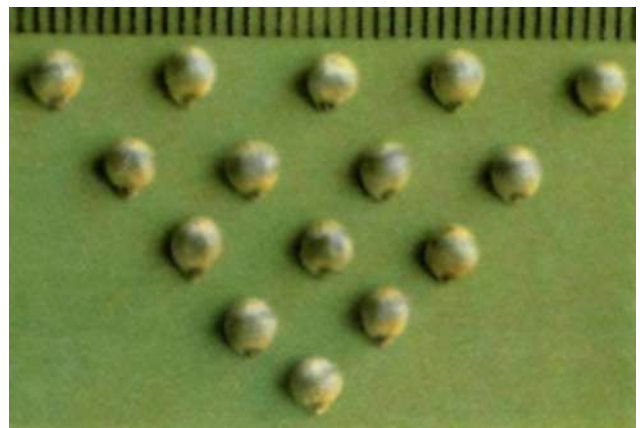
Stage 9 : Physiological maturity

Physiological maturity is marked by the formation of a small black layer in the hilar region of the seed (Fig. 9). The formation of this layer coincides with the cessation of movement of materials into the grain, and hence with the cessation of grain growth. Black layer formation begins from the upper part of the panicle (as does stigma emergence) and proceeds down the panicle. By this stage the grain has achieved its maximum dry weight, has partly dried, and the endosperm is becoming hard.

Growth and Development of Individual Organs

The previous section described the development of the pearl millet plant as a whole. This section describes the growth and development of individual plant parts (roots, leaves, etc). The data are taken from studies on Mil Zongo and BK-560, a new hybrid released by the All India Coordinated Millet Improvement Program. (BK-560 was substituted for

Figure 9. Growth stage 9 : Physiological maturity. The small black layer is visible in the hilar region at the base of each grain.



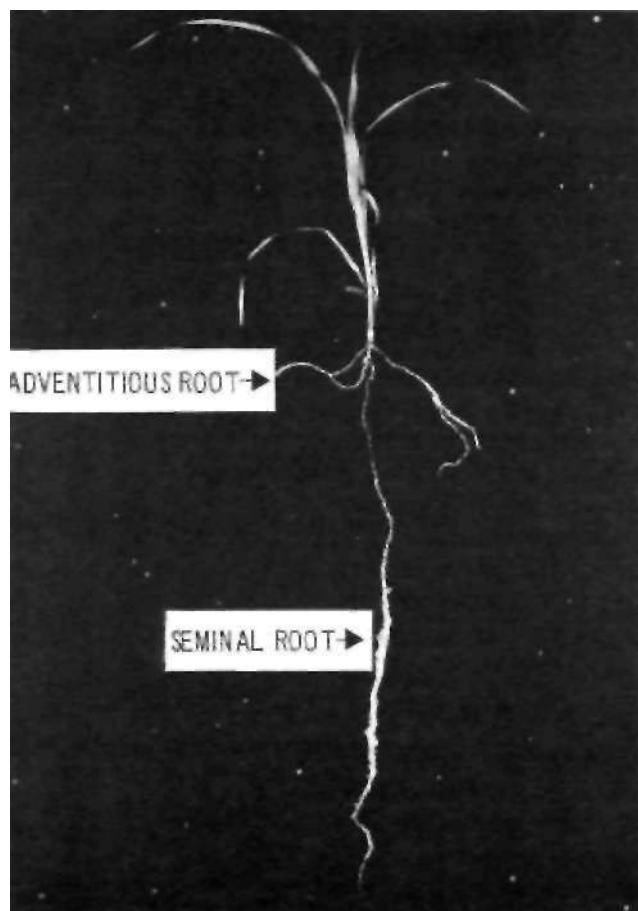
HB-3 in these studies because of the disease susceptibility of the latter. BK-560 is of equivalent maturity and has a similar plant type to HB-3.)

Root development

The root system in pearl millet has three components: (1) the seminal root, or the primary root, derived directly from the radicle; (2) the adventitious roots, which develop from nodes at the base of the stem; and (3) the crown (or collar) roots, which originate from several lower nodes of the stem at or above the soil surface.

The seminal root system can be easily identified because its main axis (the radicle) is thinner than the adventitious roots and it produces an extensive system of fine laterals. These laterals develop within 3-4 days after the radicle emerges from the seed and are visible as fine branches along the length of the axis (Fig.10). They elongate and develop rapidly,

Figure 10. Root development 1 : The seminal and adventitious roots at approximately 15 days after emergence.

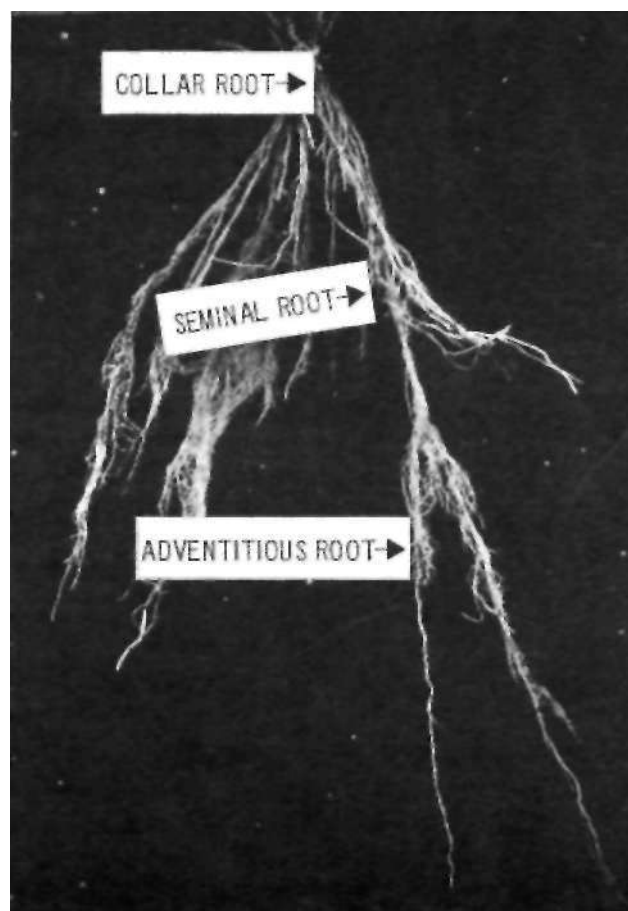


forming the main support of the plant during the seedling stage. The seminal root system generally remains active up to 45-60 days, after which it decays.

The adventitious roots begin to appear 6-7 days after seedling emergence in the nodal region at the base of the seedling (Fig. 10). They can be distinguished from the seminal root by their generally greater diameter, and by their point of initiation at the base of the stem. They vary in number from three to five per shoot. They rapidly develop a very extensive system of secondary and tertiary branches and are the main pathway for supplying water and nutrients to the plant during most of its life.

The crown (or collar) roots develop in the lower nodes of the stem near the soil surface approximately 30 days after the emergence of the seedling (Fig. 11). They are considered to serve mainly as support for the stem, but have been

Figure 11. Root development 2: The crown, seminal and adventitious roots at approximately 30 days after emergence.



observed to develop many lateral branches by the time of flowering. These appear to be active in the uptake of water and nutrients. The development of the plant's root systems 60 days after emergence is shown in Figure 12.

Tiller development

The tiller initials or buds develop in the axils of the lower leaves and are initially enclosed by the leaf sheath. The first tiller leaf appears about 12 days after emergence in the axil of the coleoptile. Subsequent tillers develop on alternate sides of the main shoot following the alternate arrangement of leaves on the shoot (Fig. 13). The development and growth of the tillers follows a pattern identical with that of the main shoot. The tiller development may be either nearly synchronous with the development of the main shoot or may be considerably delayed, or even suppressed by the main shoot. The number of tillers reaching flowering is a function of both the variety and the environmental conditions, particularly the spacing between the plants.

Some varieties produce tillers (called nodal tillers) from the upper nodes of the main stem after grain set in the main panicle. These have a short developmental cycle, producing only a few leaves and usually a small panicle. Nodal tillers are common when grain set on the main panicle is poor or the main panicle is damaged in some way.

Tillers in both BK-560 and Mil Zongo started to

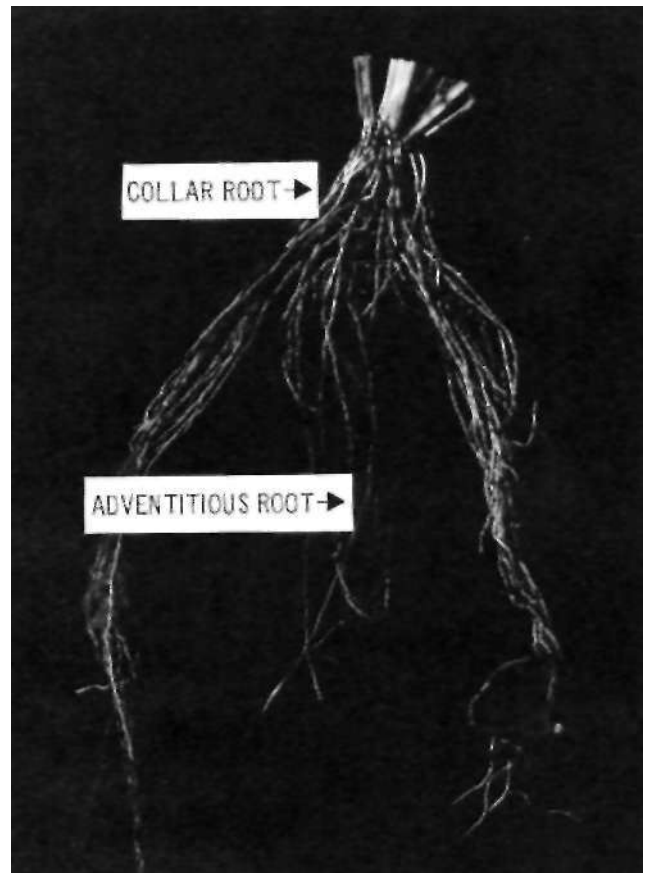


Figure 12. Root development 3 : The crown and adventitious roots at approximately 60 days after emergence.

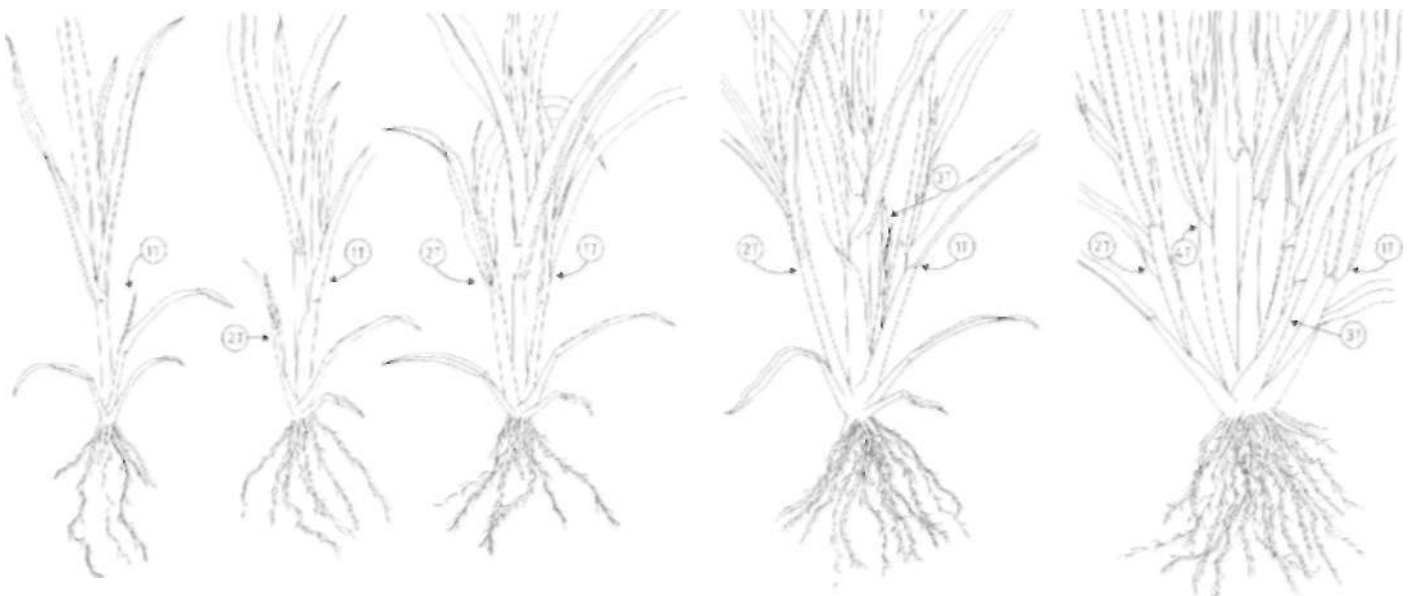


Figure 13. The sequential development of tillers : 1T= first tiller; 2T= second tiller; etc.

emerge 10 days after the emergence of the coleoptile and the maximum tiller number was reached by 25-30 days (Fig. 14). Of the six tillers produced by BK-560, three to four formed heads; but only one or two of the five tillers produced by Mil Zongo formed heads.

Leaf area development

The five embryonic leaves (those which were within the embryo itself at the time of germination) emerge at the rate of approximately one leaf per day. Rates of emergence of the subsequent leaves (which are initiated after germination) decline slowly, reaching a seasonal average rate of 0.40-0.45 leaves per day by the time of final leaf emergence. The rate of emergence and the final number of leaves varies somewhat among varieties, with earlier varieties generally having fewer leaves and a faster rate of leaf emergence.

The rate of development of the total leaf area per plant is a product of the rate of leaf expansion and the size and longevity of the individual leaves for both the main shoot and the tillers. Rate of leaf area development is slow early in the season (Fig. 15a and b) because of the small size of the embryonic leaves, but increases rapidly approximately 15-20 days after emergence, as the size of individual leaves increases and as the tillers begin to expand their leaves. Maximum leaf area is attained at approximately 50% flowering, by which time the majority of the tillers have expanded all their leaves. The contribution of the tillers to the total leaf area varies among varieties, depending on the number of tillers that complete development.

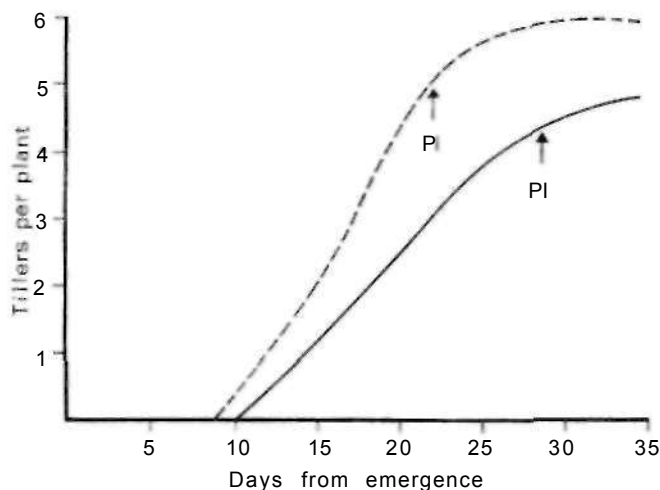


Figure 14. Time course of tiller emergence in BK-560 (broken line) and Mil Zongo (solid line). PI indicates the time of panicle initiation.

Following flowering there is a steady decline in leaf area as the older leaves begin to senesce. By the time of physiological maturity there generally remain only three to four green leaves per shoot.

Stem elongation

Elongation of the stem internodes begins shortly after panicle initiation, starting with the short basal internodes, followed by the longer upper internodes, and finally the peduncle. This produces

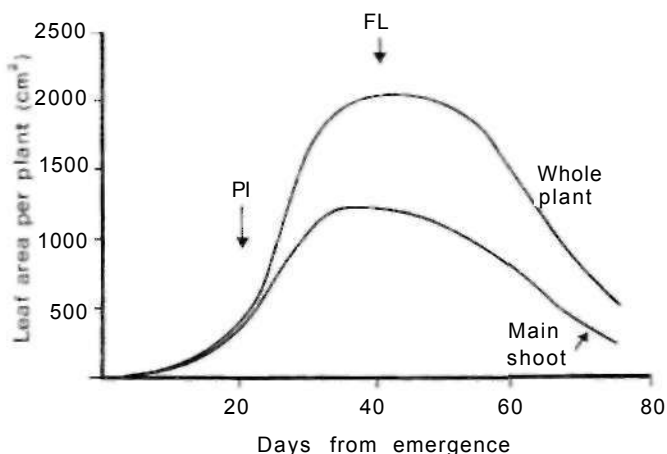


Figure 15a. Time course of leaf area development for the main shoot and the whole plant in BK-560. PI indicates panicle initiation and FL 50% stigma emergence.

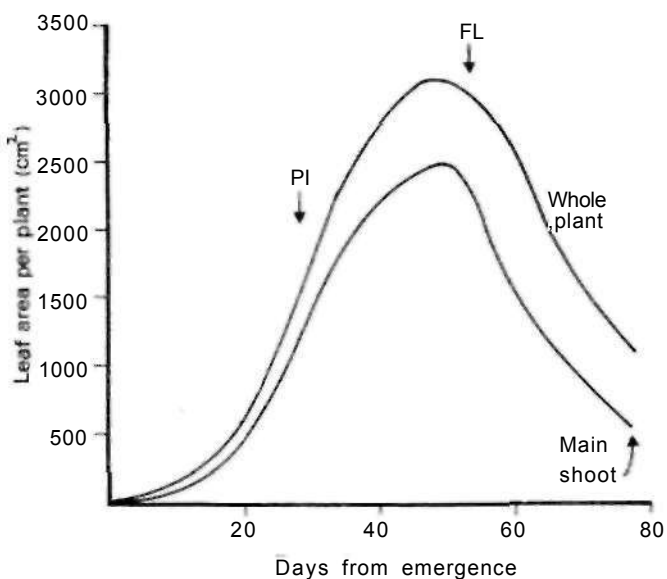


Figure 15b. Time course of leaf area development in the main shoot and the whole plant in Mil Zongo. PI indicates panicle initiation and FL 50% stigma emergence.

the common sigmoid pattern of stem elongation, with the maximum rate of elongation occurring around flag leaf stage (Fig. 16). There may be a further increase in stem length following flowering in some varieties due to continued elongation of the peduncle. Taller and/or later varieties undergo a longer period of stem elongation, due to either longer internodes or a larger number of internodes or both, and reach a greater height, but the general pattern and rate of elongation are similar.

Panicle development

The process of panicle development consists of a sequence of developmental processes, one for each of various panicle structures, which proceed from the base of the apex to the tip in regular succession. These processes are listed with their approximate time intervals, for HB-3, in Table 2.

The change from the vegetative to the reproductive apex is marked by the formation of a constriction at the base of the apex (Fig. 4). Branch primordia initiation begins at the base of the panicle within 1-2 days after floral initiation and proceeds rapidly up the panicle, reaching the apex in about 3 days. Each branch primordium rapidly subdivides to form two spikelet and several bristle primordia. This second stage of differentiation follows an acropetal pattern similar to the branch primordia differentiation.

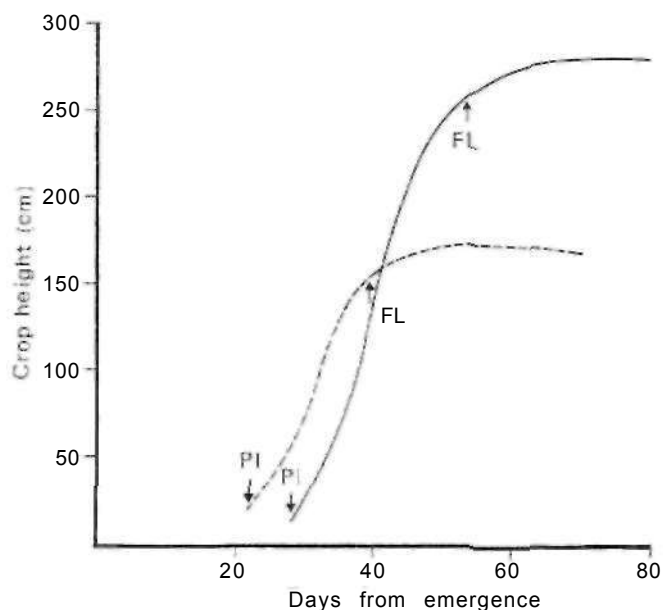


Figure 16. Time course of stem elongation in BK-560 (broken line) and Mil Zongo (solid line). PI indicates panicle initiation and FL 60% stigma emergence.

The floret primordia are then formed by a division of the spikelet primordia, which begins about 6 days after panicle initiation (Fig. 17). This is

Table 2. Panicle development stages in pearl millet variety HB-3 (from the All India Coordinated Millet Improvement Project).

Developmental stages	Developmental process	Time interval (days after emergence of seedlings)
1.	Initiation of panicle meristem	22
2.	Initiation of branch primordia at the base of panicle meristem	23-24
3.	Completion of branch primordia initiation (at the apex of the panicle meristem)	25
4.	Formation of floret primordia at the base of the panicle	28
5.	Initiation of glumes at the base of the panicle	28
6.	Initiation of the lemma and palea at the base of the panicle	30
7.	Stamen initiation at the base of the panicle	30
8.	Completion of stamen development (at the tip of the panicle)	31
9.	All floral parts developed	31-32

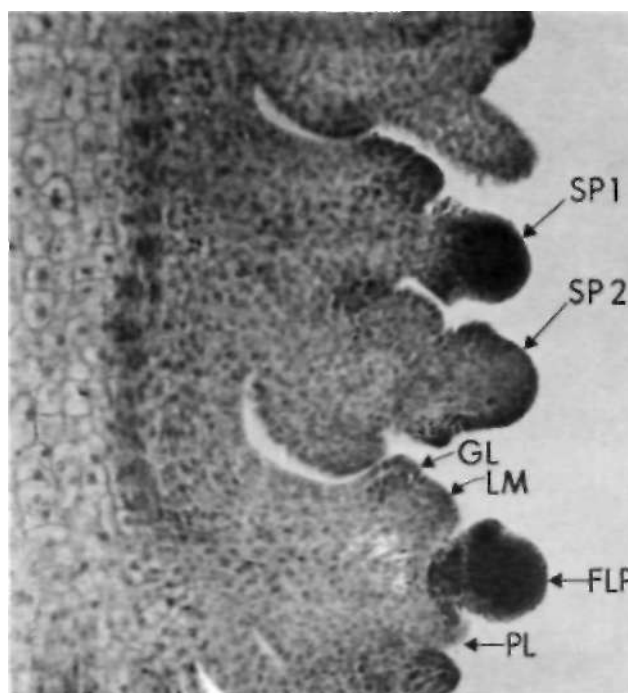


Figure 17. Photomicrograph of a developing panicle, approximately 8 days after panicle initiation. SP1, SP2 = Paired spikelets; GL = glume; LM = lemma; FLP = floret primordium; and PL = palea.

followed by the development of the glumes and the elongation of the spikelet stalks. Initiation of the floral parts (lemma, palea, stamens, and stigmas) begins at the base of the panicle about 8 days after floral initiation and is completed at the apex of the panicle by about 10 days after initiation. In most varieties there are two florets per spikelet—one perfect (containing both anthers and stigmas) and one male (containing only anthers). The distinction between these is evident as soon as the floret primordia become recognizable. The difference in flowering of these is illustrated in Figure 18.

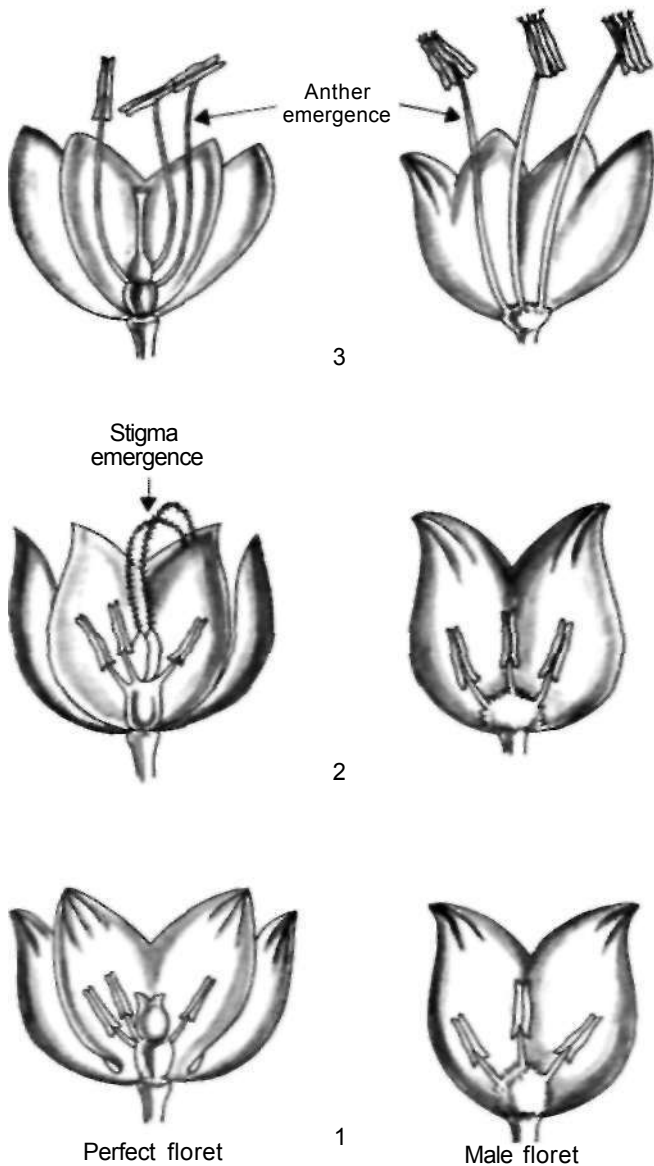


Figure 18. Flowering sequence in the perfect (left) and male (right) florets.

Grain growth

The increase in dry weight in the grains in an individual panicle follows a normal sigmoid pattern. There is an initial lag period of 5-6 days during which there is an active division of cells in the endosperm, but during which there is little increase in dry weight in the grain (Fig. 19). Following this there is a longer period of rapid accumulation of dry weight until black layer development, after which there is no further increase in grain weight. The most rapid rate of dry weight increase in the grain thus occurs during the milk to dough stages.

There is some variation in both grain size and the time to physiological maturity among grains in different locations in the panicle. Typically both are greater at the base of the panicle than in the center or the apex, and frequently greater at the center than at the apex. There is also considerable variation in grain size among varieties, from as little as 3-4 g per 1000 grains to as high as 10-12 g. Mature grains vary somewhat in shape, being generally roundish at the upper, exposed end and narrow at the hilar region. Colors vary from white to gray to brownish. The black layer is located just above the hilar region on the basal abgerminal side and the embryo is opposite (Fig. 20).

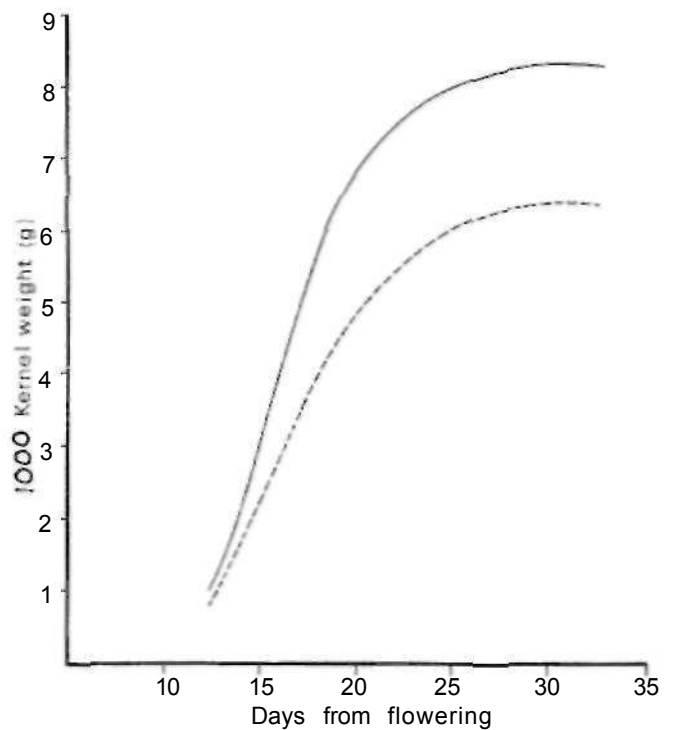


Figure 19. Time sequence of grain growth in BK-560 (broken line) and Mil Zongo (solid line).

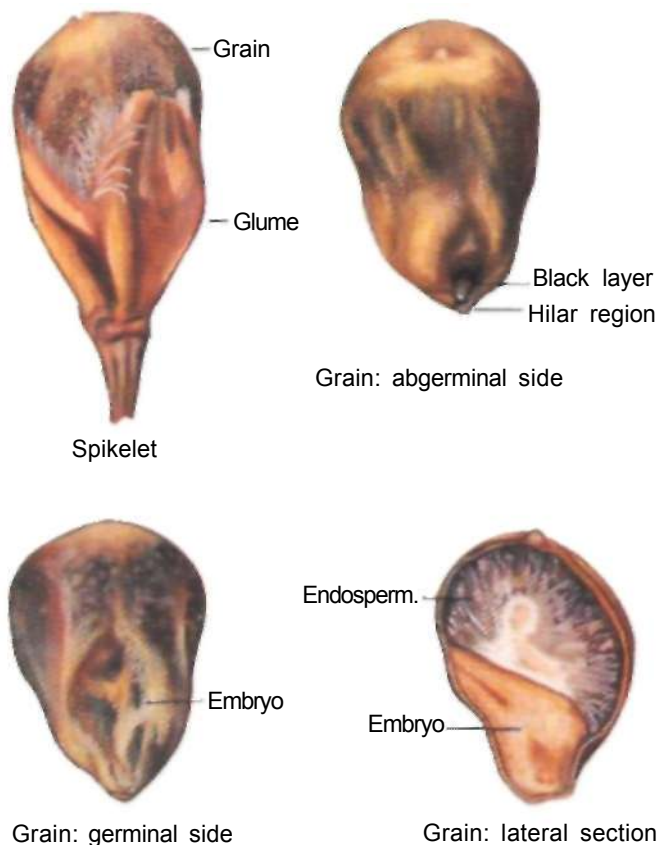


Figure 20. Spikelet and grain of *Mil Zongo*.

Distribution of plant dry weight

Rates of dry-matter accumulation during GS, are slow (Fig. 21) because of the small leaf area of the plant (Fig. 15). The majority of dry matter produced during this phase goes into the leaves and roots. Leaf growth continues during the GS₂ phase as first the main shoot and then the tillers expand their remaining leaves. By the time of flowering, however, leaf growth in the majority of the tillers as well as in the main shoot is completed, and leaf dry weight remains constant (or decreases slightly as lower leaves senesce) for the remainder of the life of the plant.

Stem elongation begins shortly after floral initiation and an increasing fraction of the total plant dry matter goes to the stem during the GS₂ phase (Fig. 21). By the time of flowering in the main shoot, approximately two-thirds of the plant dry weight is in the stem. Stem dry weight of the whole plant may continue to increase following flowering on the main culm as many of the tillers are still undergoing rapid stem elongation. There may also be some gain or loss in the dry weight of the stem during grain

filling, if the need for carbohydrates for filling the grain is either less than or greater than the available supply from photosynthesis in the leaves. Under such conditions, the stem serves as either a store for excess carbohydrate or a source of supply of carbohydrate for grain filling.

There is relatively little dry-matter distribution to the panicle during GS₂ as the panicle does not undergo rapid growth until the end of this phase (Fig. 21). During GS₃, however, the largest dry-matter increase in the plant is in the panicle, as

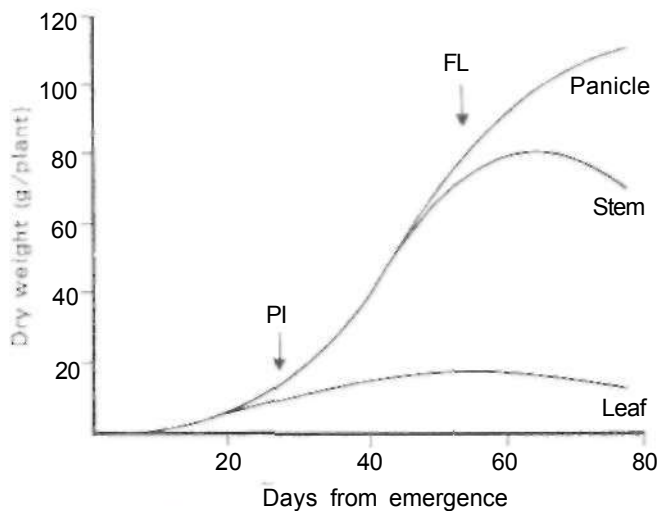


Figure 21a. Time course of dry matter accumulation in the leaf, stem, and panicle of *Mil Zongo*. PI indicates panicle initiation and FL 50% stigma emergence.

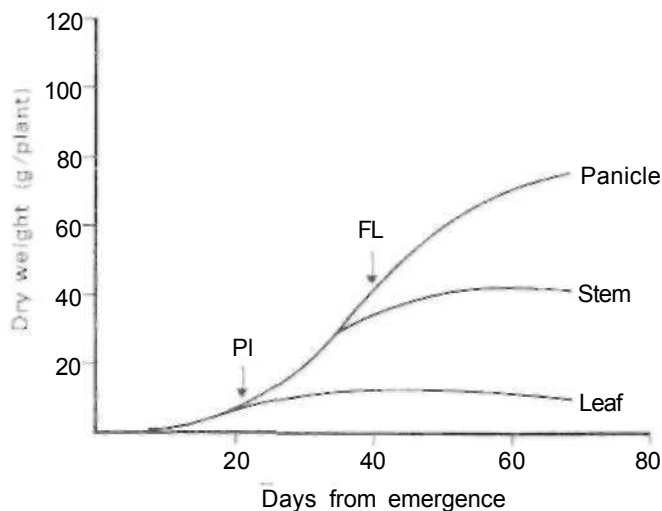


Figure 21b. Time course of dry matter accumulation in the leaf, stem, and panicle of *BK-560*. PI indicates panicle initiation and FL 50% stigma emergence.

the tillers reach flowering and the grains fill in all panicles.

The final distribution of dry matter in leaf, stem, and panicle varies rather widely in pearl millet, depending upon the variety. In dwarf, high-yielding varieties as much as 50% of the dry matter may be in the panicles, with the remainder divided between the stems and the leaves in an approximately 3 : 1 ratio. In some tall varieties, however, 50% or more of the dry weight may be in the stems, with no more than 20-30% in the panicles. Total dry-matter production in these types, however, may be considerably greater than in the dwarf varieties and actual dry weight in the panicles may be similar to that in the dwarf varieties.

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The following is a selected list of references on various aspects of the growth and development of pearl millet. They will provide the interested reader with more detailed information on the subjects they cover.

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