International Institute of Tropical Agriculture
International Maize and Wheat Improvement Center

Morphology and growth of maize

Jennifer G. Kling, Gregory Edmeades

Research Guide 9

IITA/CIMMYT Research Guide 9

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Morphology and growth of maize

Objectives. This guide is intended to enable you to:

- describe the maize plant and its importance
- define the growth stages of maize
- describe morphological features and functions of a maize plant through the stages of seedling growth, vegetative growth, flowering, fertilization and grain filling

Study materials

- Maize seeds.
- Plants at different growth stages.
- Ear shoots at various stages of development.
- Plant and ear samples of different maize varieties.
- Slides identifying different plant parts.
- Slides of various stages in the maize life cycle.

Practicals

- Identify growth stages.
- Dissect seeds, seedlings and plants, and identify morphological features.
- Identify various stages of maize ear development.
- Compare varieties and describe distinguishing characteristics.

Questions

1 To what plant family does maize belong?
2 Why is maize botanically unique among cereal crops?
3 Where is the origin of maize?
4 What is the genetic origin of maize?
5 What is the yield of maize in different parts of the world?
6 How do scientists divide growth stages into categories?
7 What does ‘n’ represent in the definition of growth stages?
8 What are three main components of the maize kernel? What are their functions?
9 What is the protein content of the maize endosperm?
10 What are the two types of maize endosperm?
11 Describe the germination process in maize.
12 What is the difference between seminal and adventitious roots?
13 Where does the main root system of maize develop from?
14 Where is the growing point located in maize, 2 weeks after planting?
15 Where is the leaf connected to the stem?
16 When are the last maize leaves initiated?
17 What depth can maize roots reach?
18 What does ‘monoecious’ mean?
19 For how many days do maize tassels produce pollen?
20 How many pollen grains can a maize plant produce?
21 How many ear shoots does a maize plant initiate?
22 How many kernels can a typical maize ear potentially produce?
23 What are the three stages of grain filling?

Morphology and growth of maize

Abstract. Maize is one of the most important food crops worldwide. It has a remarkable productive potential. However, considerable variation exists among varieties in morphology and growth habit. Management of a maize crop with respect to interaction of genotype and environment requires specific knowledge of maize growth and development.

1 The maize plant and its importance

Maize (*Zea mays* L.) and all major cereal crops are members of the grass family, Gramineae. Worldwide, wheat, rice and maize are produced in greater quantities than any other crops. Of these crops, maize has the highest average yield per hectare (Table 1). Maize is third after wheat and rice in area harvested and total production.

Maize has the basic structure of the grass family (Figure 1), with conspicuous nodes and internodes on the stem. The leaves grow on opposite sides; one leaf per node. Maize is botanically unique among cereal crops. It is monoecious (separate male and female inflorescences on the same plant) and produces grains on lateral rather than terminal branches. Maize is a cross-pollinating (allogamous) species; therefore, a natural population is usually heterogeneous.

Table 1. World production of major cereal crops (FAO 1993).

Crop	Area harvested (million ha)	Yield (t/ha)	Total production (million t)
Wheat	222	2.5	564
Rice	148	3.6	527
Maize	127	3.7	471

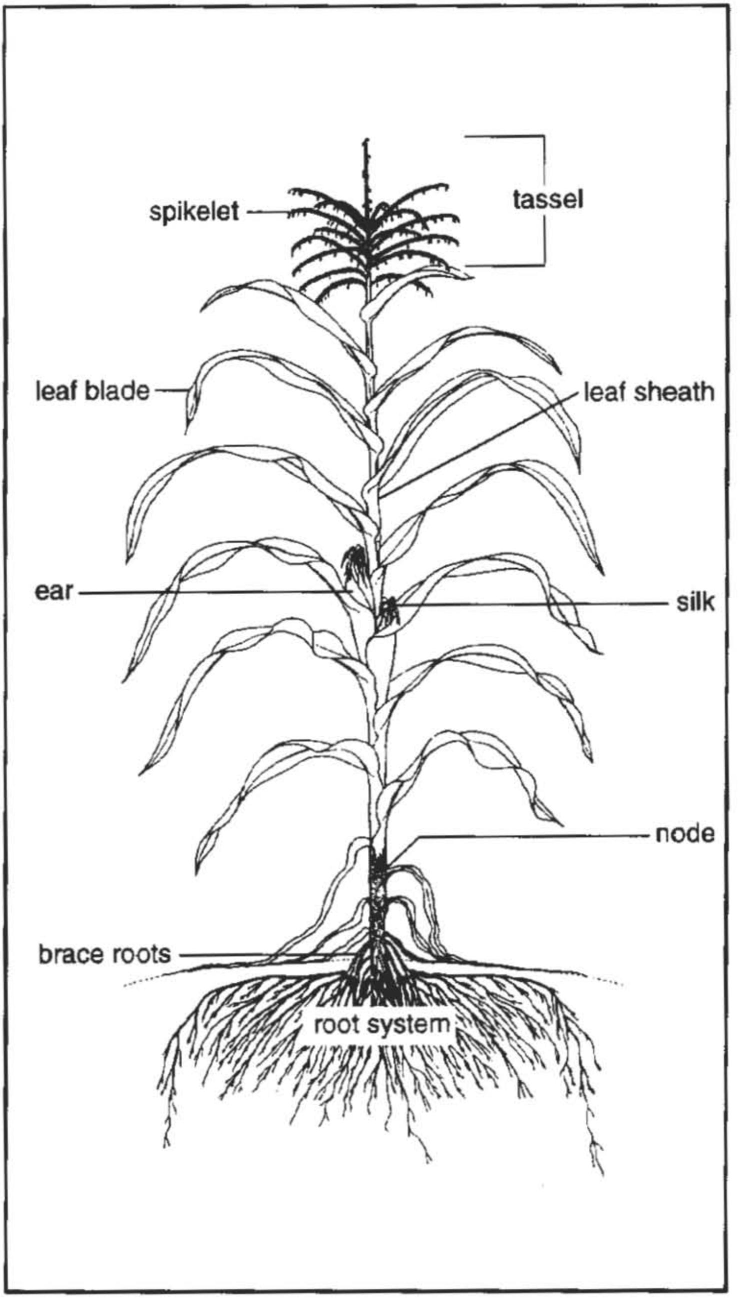


Figure 1. The maize plant.

The origin of maize has been a matter of controversy. The most common opinion is that maize originated through domestication of the wild grass teosinte (*Zea mexicana*), which is native to Mexico, Guatemala, and Honduras.

Considerable cross-pollination between maize and teosinte has occurred during their evolution. However, since the two species differ considerably in appearance, some researchers maintain that maize must have originated from a wild pod corn that is now extinct. The first maize cobs that are still preserved are about 7000 years old and were found in a cave in Mexico.

By the time the Europeans reached the Americas, maize had attained its modern form and was a staple food throughout the western hemisphere. Maize spread rapidly to Europe, Africa, and Asia through the explorers of the 16th and 17th centuries.

Today, the United States grows nearly 40% of the total world production of maize and average yield is 7.5 t/ha. Much of the maize from developed countries is used for animal feed. Africa produces about 6% of the total world production, most of which is for human consumption. In West and Central Africa, average yield is about 1 t/ha, but higher (1.5–2 t/ha) in East Africa, Asia, and Latin America.

The maize plant has a remarkable productive potential. In 9 weeks in the lowland tropics, a single seed develops into a plant 2.5–3.5 m high. Two months later, it can produce 400–700 seeds.

The maize plant described in this document is representative of a lowland tropical variety, flowering in 55–60 days and maturing in 115 days.

However, considerable variation exists among varieties in morphology and growth habit. For example, an early-maturing tropical variety may reach a height of only 1.5 m, flowering in 45–50 days and maturing in 90 days. Furthermore, environmental factors influence the length of the various growth stages.

2 Growth stages

For standardization of definitions, maize researchers developed a guide for identifying different growth stages of maize. Not all plants in a field reach a particular stage at the same time. Therefore, researchers assume that the crop reaches a specific stage when at least 50% of the plants show the corresponding features.

Standardization of definitions allows researchers to relate problems, cultural practices and other agronomic observations to specific growth stages. Researchers can also compare the phenology of maize under different environmental conditions and experimental treatments.

Researchers divide growth stages into two broad categories (Table 2):

- vegetative (V)
- reproductive (R)

The following sections give more detailed description of the growth stages:

Section 3	Seedling growth (stages VE and V1)
Section 4	Vegetative growth (stages V2, V3 ... Vn)
Section 5	Flowering and fertilization (stages VT, R0, and R1)
Section 6	Grain filling and maturity (stages R2 to R6)

Table 2. Growth stages.

Stage	DAS*	Features
VE	5	The coleoptile emerges from the soil surface
V1	9	The collar of the first leaf is visible
V2	12	The collar of the second leaf is visible
Vn		The collar of leaf number 'n' is visible. The maximum value of 'n' represents the final number of leaves, which is usually 16–23, but by flowering, the lower 4–7 leaves have disappeared
VT	55	The last branch of the tassel is completely visible
R0	57	Anthesis or male flowering. Pollen shed begins
R1	59	Silks are visible
R2	71	Blister stage. Kernels are filled with clear fluid and the embryo can be seen
R3	80	Milk stage. Kernels are filled with a white, milky fluid
R4	90	Dough stage. Kernels are filled with a white paste. The embryo is about half as wide as the kernel. The top part of the kernels are filled with solid starch
R5	102	Dent stage. If the genotype is a dent type, the grains are dented. The 'milk line' is close to the base when the kernel is viewed from the side in both flint and dent types
R6	112	Physiological maturity. The black layer is visible at the base of the grain. Grain moisture is usually about 35%

*DAS: approximate number of days after sowing in lowland tropics, where maximum and minimum temperatures may be 33 °C and 22 °C, respectively. In cooler environments, these times are extended.

3 Seedling growth

The structure of a maize kernel is typical of the grass family (Figure 2). The kernel is a hard, one-seeded fruit called a caryopsis. It consists of:

- pericarp
- endosperm
- germ (embryo)

Pericarp. The pericarp is a protective outer layer, derived from maternal tissue.

Endosperm. The endosperm constitutes the major portion of the kernel (about 82–84% dry weight), and serves as energy reserve for the growing seedling. The endosperm is about 88% starch and 8% protein.

There are two types of endosperm, flinty (hard) and floury (soft). The distribution of flinty and floury endosperm depends on variety and climatic conditions. Dent varieties have flinty endosperm on the sides of the kernel, and a central core of floury endosperm. The floury portions shrink when dry, and the tip of the kernel becomes depressed or dented.

In contrast, flint varieties have flinty endosperm over the tip of the kernel. Therefore, the crown of the kernel does not shrink as it dries.

The outermost layer of the endosperm is called the aleurone. The aleurone layer produces enzymes that convert starch to sugar. The developing seedling uses the sugar as energy.

Germ (embryo). The germ comprises 10–12% of total dry weight of the kernel. The germ consists of embryo axis and scutellum (Figure 3). The embryo axis contains both the shoot and root primordia.

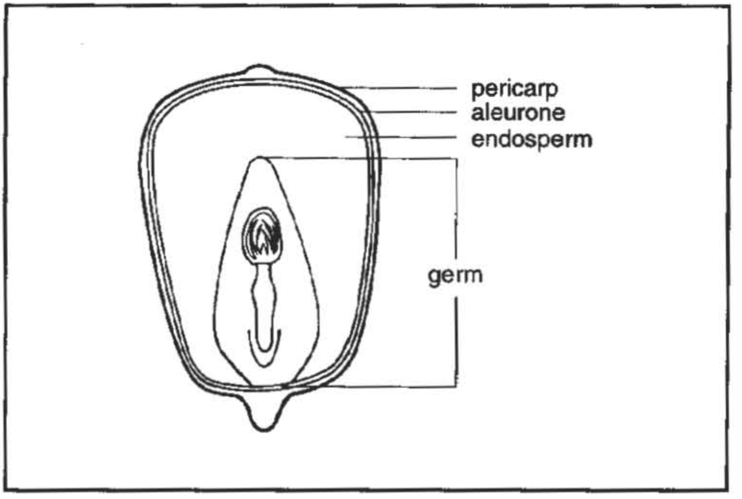
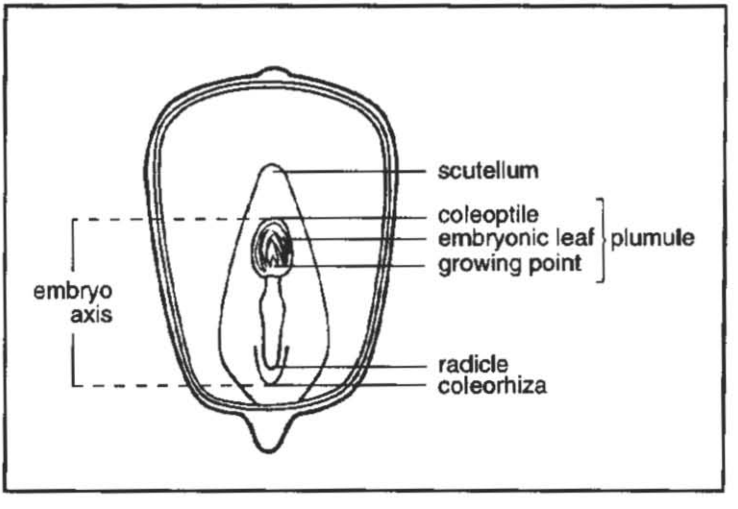


Figure 2. Maize kernel (longitudinal section).

Figure 3. Maize germ.



The scutellum helps the seedling to digest and absorb starch from the endosperm. The shoot primordium consists of about 5 embryonic leaves, the stem and growing point (apical meristem), and a protective sheath for the growing shoot, called the coleoptile.

The embryonic leaves and the stem are collectively called the plumule. The root end of the embryo axis contains the radicle (first root), several lateral root initials, and a protective sheath called the coleorhiza.

The germ contains about 8% starch, 18% protein and 33% oil. The germ contributes most of the oil, sugar, and ash (including minerals and vitamins) in the kernel.

Germination. As soon as the seed absorbs water, certain chemical changes occur. The aleurone layer releases enzymes which convert starch in the endosperm into sugar, thereby providing energy for seedling growth.

The radicle elongates first, emerging from the seed coat. Then the shoot elongates and the coleoptile breaks through the seed coat to complete germination. Elongation of the first internode (mesocotyl; Figure 4) pushes the coleoptile upward towards the soil surface. The seed remains in the soil. Therefore, germination in maize is hypogeal.

The coleoptile emerges from the soil 6–10 days after planting (growth stage VE) and soon stops growing. Sunlight at the soil surface stimulates the plumule to grow and break through the coleoptile.

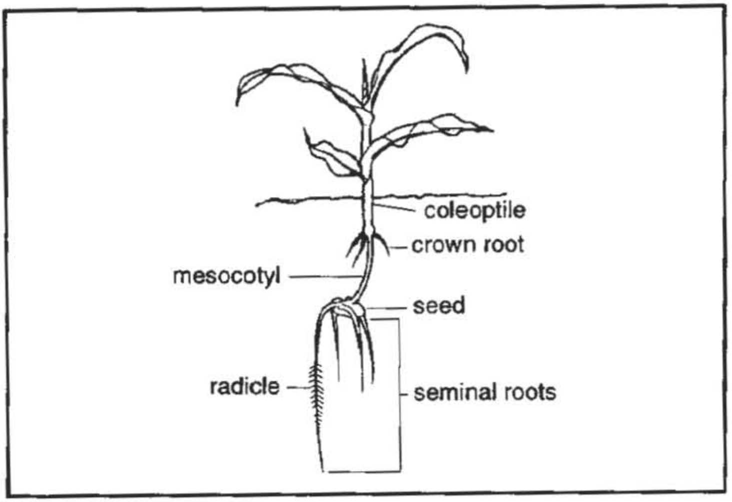
The coleoptile is the fine green shoot observed when maize is first emerging from the ground. The coleoptile should not be confused with true leaf number 1 which has a rounded tip.

The young seedling develops several lateral roots which, with the radicle, comprise the seminal roots (Figure 4). The initials of these seminal roots are already present in the embryo.

Although the seminal roots make up a small proportion of the total root mass, they play an important role in anchoring the seedling and providing water and nutrients for early growth.

The main root system develops from the crown, which is just below the soil surface. The crown roots develop shortly after the seedling emerges.

Figure 4. Maize seedling 2 weeks after sowing.



Appearance of the collar of the first leaf (stage V1) marks the end of seedling growth. From this stage on, the endosperm becomes less important as a source of food for the young plant. The plant can now photosynthesize on its own.

4 Vegetative growth

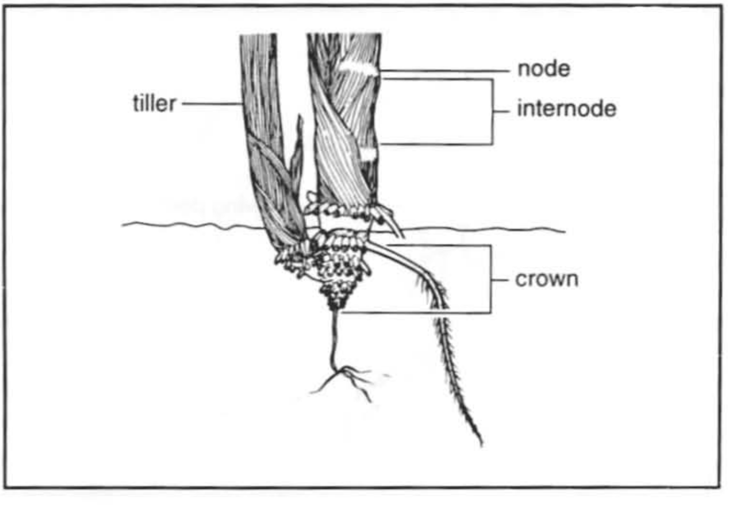
Vegetative structures include:

- stem
- leaves
- roots

Stem. The stem consists of alternating nodes and internodes. Several nodes and internodes remain condensed underground, forming the crown (Figure 5). Above the crown, internodes elongate resulting in a stem length of 2.5 m or more under favorable conditions.

The lower nodes of the stem form lateral branches. The lateral branches may develop into tillers which are like full maize plants (Figure 5). Often, tillers do not have ears and are shorter than the main stem.

Figure 5. Crown and tiller.

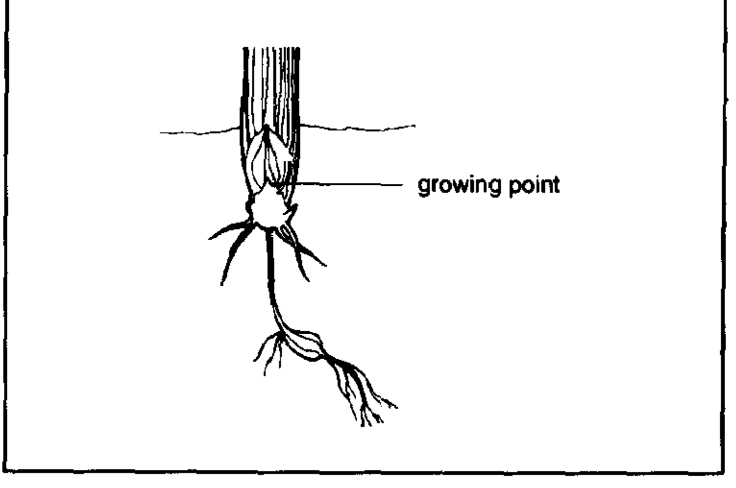


In the lowland tropics, tillers rarely form, or if they do, rarely grow to full height.

The upper nodes develop lateral branches that become either functional or rudimentary ear shoots. All branches form terminal infloresccnses, which can be male (tassels) or female (ear shoots).

The growing point is at the tip of the stem (Figure 6). It remains underground for the first 3–4 weeks after planting. If the plant breaks off at ground level when the growing point is underground, a new plant can still regenerate. However, a plant that breaks below the growing point does not regenerate.

Figure 6. Growing point.

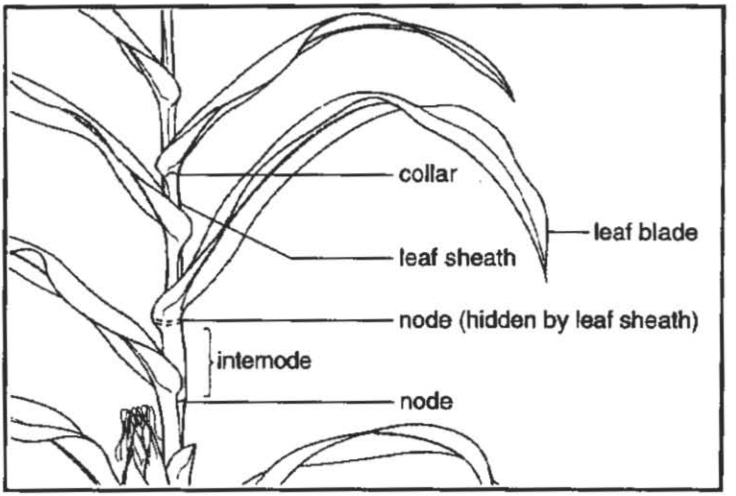


Leaves. A single leaf grows from each node. The leaves grow from opposite sides of the plant in an alternating pattern. Each leaf consists of leaf sheath, leaf blade, and collar (Figure 7).

The collar is a distinct joint which marks the point of extension of leaf blade from the leaf sheath. The appearance of the collar indicates that a leaf blade is fully extended. The leaf is connected to the stem below the collar, where the leaf sheath is attached to the node. Leaf sheaths support the plant before and during elongation of internodes.

All leaves are initiated within the first 4–5 weeks after planting. As the internodes elongate, a 'new' leaf emerges from the whorl once every 3 days (depending on the temperature), with a total of 16–23 leaves, depending on genotype and environment (specifically daylength and temperature).

Figure 7. Leaves.



A new leaf appears about every 5 days in cooler, highland environments.

The first leaf has a rounded tip; all subsequent leaves are pointed. The first 4–7 leaves decay and disappear, and are no longer identifiable 4–5 weeks after planting. The last leaf emerges shortly before tasseling.

Number of leaves is generally used to describe different stages of vegetative growth (Vn). For example, the 10-leaf stage is V10.

Although the convention is to count the number of fully extended leaves (leaves showing collars), it may be easier to count visible leaf tips. Also, number of visible leaf tips is a linear function of accumulated heat units from time of sowing, whereas appearance of leaf collars is not linearly related to heat units.

Roots. Roots originating from the stem tissue are called adventitious roots. They grow from the nodes that constitute the crown. Adventitious roots also grow from successive nodes near the ground (Figure 8), and are called brace roots. Most brace roots form after tasseling, and concentrate in the topsoil.

By the 8th week, the root system may be well developed, extending into the area between rows and reaching 45 cm depth. Cultivation between the rows at this stage can damage the plants.

Roots grow laterally in the upper soil and then turn vertically downwards (Figure 9).

As the plant grows, individual roots may reach a depth of 2.5 m in good soil.

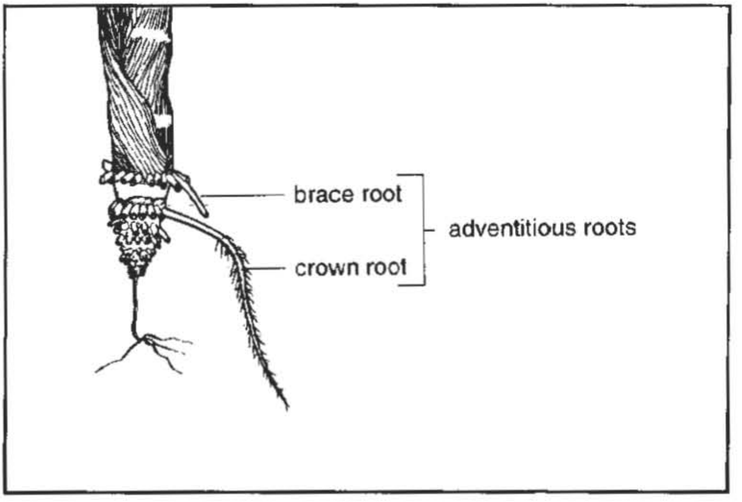
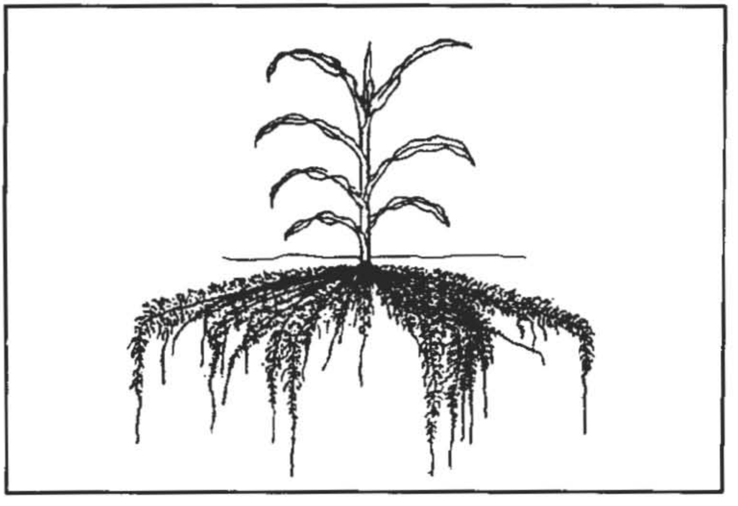


Figure 8. Adventitious roots.

Figure 9. Root system.

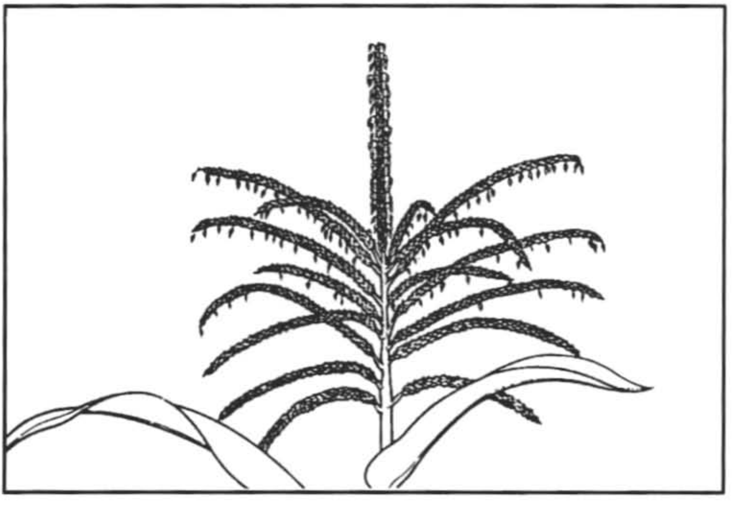


The maize plant is monoecious, bearing male flowers in the tassel and female flowers on the lateral ear shoots of the same plant.

Tassels. Approximately 30 days after sowing, when the stem is only 2 cm long and the plant just knee-high, the tassel is initiated. At this stage, the growing point switches from producing leaves to producing the terminal reproductive structure, the tassel.

Approximately 50 days after germination and several days before pollen-shed, the top internodes elongate and the tassel emerges from the leaf whorl (Figure 10). The maize plant reaches the VT growth stage when the last branch of the tassel is completely visible.

Figure 10. Maize tassel, during anthesis.

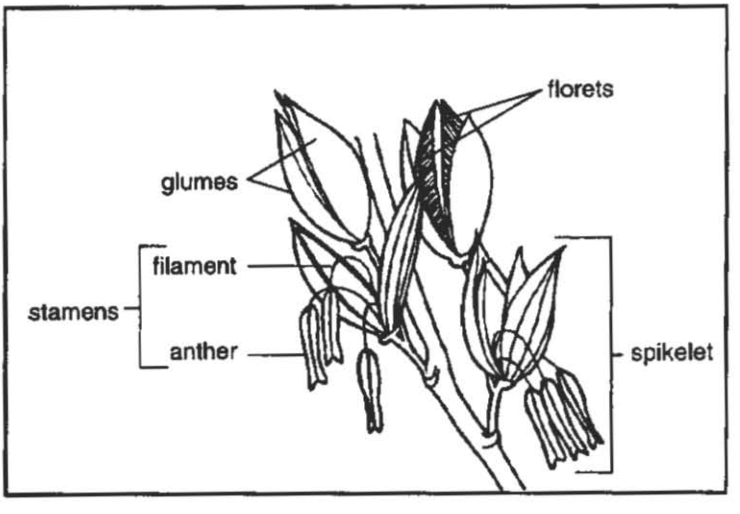


Pollen is produced in the male spikelets of the tassel. Each spikelet consists of a pair of flowers (florets) enclosed in two large glumes (Figure 11). The florets contain stamens that produce the pollen grains.

Anthers and filaments make up the stamens. Under favorable conditions, the anthers emerge; generally mid-morning. Anthers break open at the tips, resulting in pollen-shed (anthesis; Figure 10).

Anthesis (R0) is a useful growth stage to observe, because it marks the transition to the reproductive phase, and is less sensitive to environmental factors than silking (R1).

Figure 11. Male spikelet.



The pollen does not usually move far unless there is adequate wind to promote cross-fertilization. In unfavorable conditions (for example, very high temperatures or cold, rainy weather), there may be no pollen-shed.

The first spikelets to open and shed pollen are those on the central axis of the tassel. Usually, pollen-shed continues in both directions from the central spikelets to both ends of the tassel.

The last spikelets to shed pollen are those at the base of the tassel. Most tassels shed pollen for 5–8 days, with pollen production reaching a peak around the third day.

A vigorous maize plant can produce 25 million pollen grains, so quantity of pollen is rarely a limiting factor in maize production.

Ear shoots. Ear shoots are initiated 6–8 nodes below the tassel and at lower nodes. Although buds occur at numerous nodes, only the top 1–3 ear shoots eventually form ears.

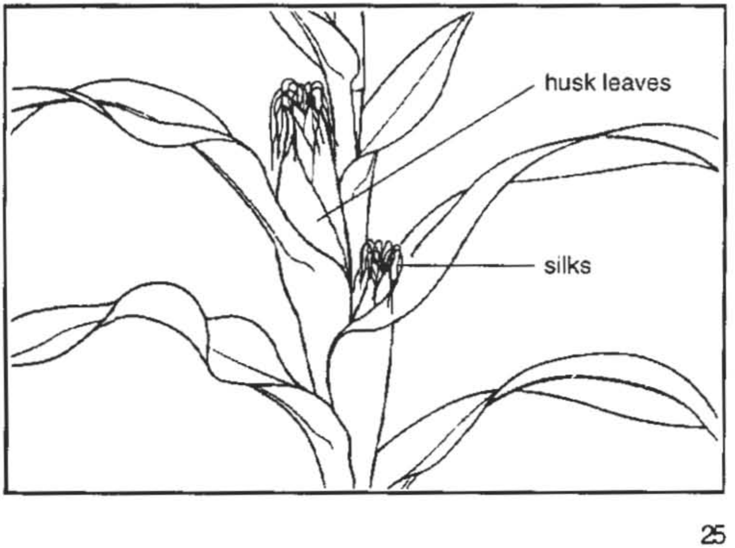
Initiation of axillary buds begins at the base of the stem and proceeds upwards. However, differentiation of buds into ear shoots proceeds from the uppermost bud towards the base of the plant.

Ear shoot initiation occurs about 10 days after tassel initiation. Ear elongation stops first at lower nodes giving top ears more time to develop and accumulate assimilates.

The internodes on lateral branches bearing the female inflorescence are shortened, so that the husk leaves overlap and cover the developing ear (Figure 12). Female spikelets are in pairs, therefore maize ears always have an even number of rows. Each spikelet contains one fertile ovule. A typical tropical maize ear has 500–750 ovules or potential kernels.

Each ovule produces a silk (style) which is stigmatic (receptive for pollen germination) for most of its length. The maize style is longer than that of any other species in the plant kingdom. The first silks to emerge from the husk are those from the base of the ear. Appearance of silks on the ear marks the growth stage R1.

Figure 12. Ears.



Because maize is usually protandrous (male flowers mature before female flowers), silks receive pollen as soon as they emerge. The period between pollen shed (anthesis) and silk emergence (stage R1) is called the anthesis–silking interval. This interval is a measure of protandry, and is related to tolerance to stresses which reduce photosynthesis at flowering.

Under favorable conditions, silks emerge 1–3 days after anthesis and remain fertile for about 1 week before senescing at their base. Harsh weather can cause silks to dry up or delay silk emergence. Poor 'nicking' (lack of synchrony of anthesis and silk emergence) is largely a result of delayed silk emergence.

Under certain conditions, when growth is vigorous and unstressed, female flowers mature before male flowers (protogyny). Fertilization and yield may not be adversely affected if anthesis occurs up to 5 days after silk emergence.

Moist, sticky hairs for catching pollen cover the silks. Pollen grains germinate within a few minutes after reaching the silks. The pollen tubes grow down the silks in 12–28 hours to fertilize the ovules.

6 Grain filling and maturity

Kernels are arranged in even numbers of rows along the rachis or cob of the ear (Figure 13). Several husk leaves protect the ear from environmental effects such as disease infection.

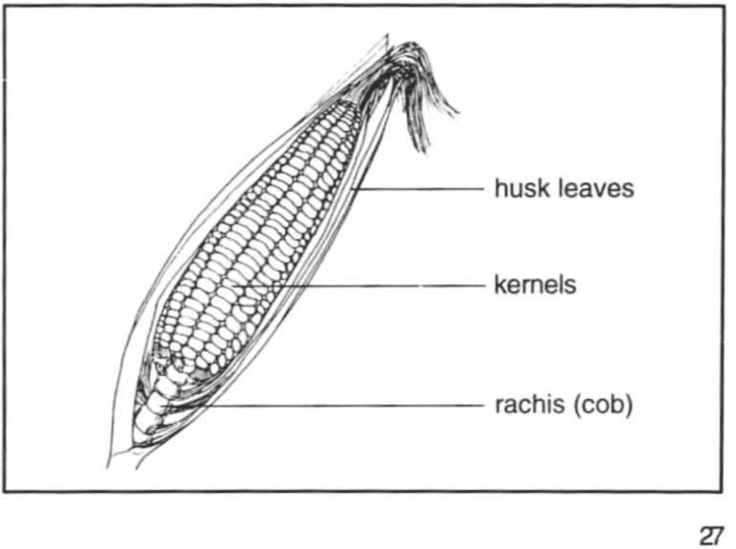
Grain filling is in three stages:

- blister stage (R2)
- milk stage (R3)
- dough stage (R4)

Maturity occurs in two stages:

- dent stage (R5) (the ear is considered mature for green ear consumption in many societies)
- physiological maturity (R6)

Figure 13. Mature maize ear.



Blister stage. After fertilization, silks wilt and turn brown. Carbohydrates and nutrients rapidly accumulate in the developing kernels in the form of clear fluid. About 10 days after flowering, kernels shaped like small blisters appear. This is the blister stage (stage R2). The embryo can be seen at this stage.

Milk stage. The milk stage (stage R3) begins 3 weeks after silking (that is, R1). The kernels are filled with a white, milky fluid. The fluid has a high sugar content and the kernels are most suitable for consumption as fresh maize. Following the milk stage, the sugar content decreases and the starch content increases. Also, water content decreases as dry matter content increases.

Dough stage. The last stage of actual grain filling may be divided into two phases:

- soft-dough
- hard-dough

At soft-dough, kernels are filled with a white paste. The embryo occupies half the width of the kernel.

At hard-dough, the white paste in the kernel gradually solidifies to starch, starting from the top part of the kernels.

A 'milk line' becomes apparent on the side of the kernel opposite the germ. The milk line separates the mature, starchy area from the milky region near the base of the kernel. The milk line moves toward the base of the kernel as the grain continues to mature.

Noting the position of the milk line is a useful way of monitoring the maturity of the kernels and anticipating time to harvest. When an ear of corn is broken in half, the milk line is seen on the exposed kernels on the tip half of the ear. When the milk line has moved about halfway down the kernel, about 95% of the final yield is attained, and the maize should be ready for harvest in 2–3 weeks. Grain moisture content is about 40%.

Note that grain moisture content is expressed on a wet basis:

% moisture = (weight of water/total grain weight) x 100

In a dent variety, the kernels start to dent. Vegetative plant tissues senesce in the late grain-filling stages as carbohydrates and nutrients are translocated to the developing kernels.

Dent stage. In dent types, 50–90% of the kernels are fully dented. The milk line is now close to the base of the kernel or may no longer be visible from the outside of the kernel.

Physiological maturity. The embryo reaches full size about 7 weeks after flowering. By the following week, the kernel is at maximum dry weight and the kernel moisture content is about 35%. When transport of assimilates to the kernel ceases, a 'black layer' (abscission layer) forms at the base of the kernel. Kernels in the middle region of the ear are the first to reach the black layer, followed by those at the tip. Kernels at the base mature last.

The ear is considered to be physiologically mature when 75% of the kernels in the central part of the ear reach the black layer.

Another way to determine maturity of the ear is by looking for milk at the base of the kernel. When liquid can no longer be expressed by pressing the kernel with a knife or fingernail, the ear is at or near physical maturity.

It is advisable to use both the disappearance of the milk line and black layer formation as indicators of physiological maturity. In general, kernels will be free of milk 2 days before the black layer begins to form. However, if maize is stressed, the black layer may form prematurely, indicating the end of dry matter accumulation, and hence physiological maturity.

Kernels at the tip of the ear are smallest. They are pollinated last and mature first, and therefore have less time to accumulate dry matter.

Although grain filling and maturity are usually categorized into discrete stages (R2–R6), these stages are sometimes difficult to identify precisely. Grain dry matter accumulation is in fact a continuous process that can be divided into:

- lag phase
- linear phase
- final phase

The three phases are shown in Figure 14.

Lag phase. This phase begins immediately after fertilization and continues until the onset of linear dry matter accumulation, about 10 days after fertilization (depending on genotype and temperature).

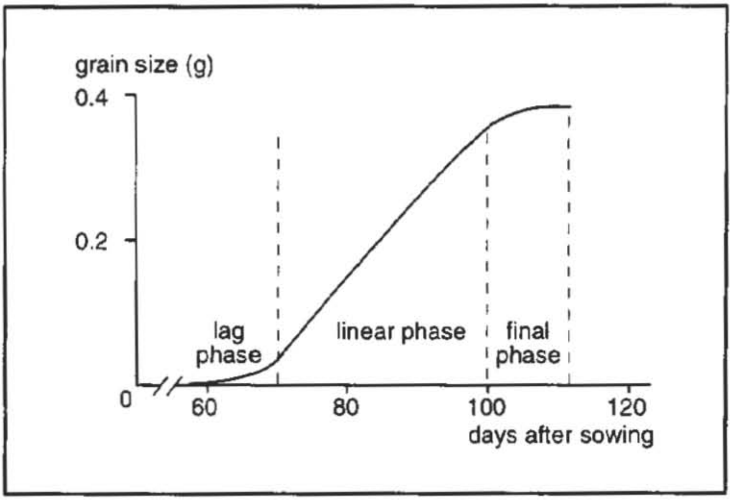
Linear phase. The linear phase is the period of rapid grain filling during which about 90% of total grain dry matter is accumulated.

Final phase. Dry matter accumulates at a decreasing rate, ending in physiological maturity and black layer formation.

Kernels continue to lose water after physiological maturity. Variety and weather determine rate of drying.

Typically in the lowland tropics, moisture loss from the grain occurs at a rate of 2–3% per week immediately after black layer formation. The rate declines exponentially until an equilibrium moisture content is reached. The equilibrium moisture content ranges from about 14% at the end of the rainy season, to 18% in a humid lowland environment.

Figure 14. Phases of grain filling.



Grains must be well dried to maintain viability in storage (no more than 14% moisture).

Mature kernels do not require a dormancy period. They can germinate as soon as growing conditions become favorable.

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8 Suggestions for trainers

If you use this Research Guide in training:

Generally:

- Distribute handouts (including this Research Guide) to trainees one or several days before your presentation, or distribute them at the end of the presentation.

- Do not distribute handouts at the beginning of a presentation, otherwise trainees will read instead of listening to you.

- Ask trainees not to take notes, but to pay full attention to the training activity. Assure them that your handouts (and this Research Guide) contain all relevant information.

- Keep your training activities practical. Reduce theory to the minimum that is necessary to understand the practical exercises.

- Use the questions on page 4 (or a selection of questions) for examinations (quizzes, periodical tests, and so on). Allow consultation of handouts and books during examinations.

- Promote interaction of trainees. Allow questions, but do not deviate from the subject.

- Respect the time allotted.

Specifically:

- Discuss with trainees, experiences and problems of maize production and research (10 minutes). You may ask a few questions from page 4 to test the knowledge of trainees.

- Present and discuss the content of this Research Guide, considering the study materials listed on page 3 (45 minutes). Have real samples of maize plants available for each trainee (or pair of trainees) as study materials on his/her table.

- You may photocopy the illustrations of this Research Guide onto transparencies for projection with an overhead projector.

- Conduct the practicals suggested on page 3 in groups (3–4 trainees per group; 2 hours). Make sure that each trainee has the opportunity to practice. Have resource persons available for each group and practical.

  Organize your practicals/demonstrations well. Keep trainees busy. Prevent trainees from scattering around the table.

International Institute of Tropical Agriculture
International Maize and Wheat Improvement Center

The International Institute of Tropical Agriculture (IITA) and the International Maize and Wheat Improvement Center (CIMMYT) are two of sixteen institutions supported by the Consultative Group on International Agricultural Research (CGIAR), which is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR is an informal association of 50 donor countries, international and regional organizations, and private foundations.

IITA seeks to increase agricultural production in a sustainable way, in order to improve the nutritional status and well-being of people in sub-Saharan Africa. To achieve this goal, IITA conducts research and training, provides information, collects and exchanges germplasm, and encourages transfer of technology, in partnership with African national agricultural research and development programs

CIMMYT is engaged in a worldwide research program for maize, wheat, and triticale. The mission of CIMMYT's maize program is to help the poor in developing countries by increasing the productivity of resources committed to maize while protecting natural resources. This will be accomplished through the preservation, improvement, and dissemination of genetic resources; the development of environmentally compatible crop management practices; the provision of research methodologies; and through training and consulting.

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