



## **GROWTH AND DEVELOPMENT OF SESAME**

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# SUMMARY OF THE PHENOLOGY OF SESAME

## VEGETATIVE PHASE



## Stages

## Page

### Germination stage

14

End point: emergence

DAP<sup>1</sup>: 0-5

Weeks<sup>2</sup>: 1-

Farmer keys:

- Wait until soil 7:00 AM is 70°F
- Judge stand after 7 days
- Watch for crusting after rain

### Seedling stage

16

End point: 3<sup>rd</sup> pair true leaf length = 2<sup>nd</sup>

DAP: 6-25

Weeks: 3-

Farmer keys:

- Stand cannot be seen from truck – walk into field
- Very slow growth, be patient
- Difficult to cultivate
- Avoid irrigations but need to if seedlings drying out

### Juvenile stage

19

End point: First buds

DAP: 26-37

Weeks: 1+

Farmer keys:

- Dramatic growth acceleration
- Can cultivate
- Start irrigation based on plant's needs
- Last stage crop can be stressed

### Pre-reproductive stage

20

End point: 50% open flowers

DAP: 38-44

Weeks: 1-

Farmer keys:

- Last chance to put tractor in field
- Irrigate as required
- If no pivot, add 2<sup>nd</sup> half of fertility
- If pivot, add 2<sup>nd</sup> third of fertility
- First capsule is high to facilitate combining

<sup>1</sup> DAP = days after planting

<sup>2</sup> Weeks = approximate number of weeks in stage

## REPRODUCTIVE PHASE



### Stages

### Page

#### Early bloom stage

21

End point: 5 node pairs of capsules

DAP: 45-52

Weeks: 1

Farmer keys:

- Irrigate as required
- If pivot, add rest of fertility as soon as possible
- Not all flowers will set capsules, do not worry about gaps
- The white part of the flower will fall off in PM



#### Mid bloom stage

22

End point: Branches/minor plants stop flowering

DAP: 53-81

Weeks: 4

Farmer keys:

- Over 70% of flowers will occur in first 2 weeks of this stage
- Irrigate as required
- It is normal to drop leaves under the canopy



#### Late bloom stage

24

End point: 90% of plants with no open flowers

DAP: 82-90

Weeks: 1+

Farmer keys:

- Last irrigation
- Leaves in light will start to fall off
- Edges of field will stop flowering last, look inside
- In multiple fields, flower termination will be the order of combining rather than order of planting

## RIPENING PHASE



#### Ripening stage

25

End point: Physiological maturity (PM)

DAP: 91-106

Weeks: 2+

Farmer keys:

- Majority of leaves will fall off
- Use of harvest aids will substantially reduce yield



## DRYING PHASE



### Stages

### Page

#### Full maturity stage

27

End point: All seed mature

DAP: 107-112

Weeks: 1-

Farmer keys:

- Use harvest aid at the end of the stage, but preferable in early next stage
- If crop goes to regrowth, use harvest aids as soon as possible



#### Initial drydown stage

29

End point: 1<sup>st</sup> dry capsules

DAP: 113-126

Weeks: 2

Farmer keys:

- Do not panic over open capsules – they are supposed to open to increase yield and quality



#### Late drydown stage

31

End point: Full drydown

DAP: 127-146

Weeks: 3

Farmer keys:

- Get combine ready
- Seed must be 6% or less moisture

## END OF PHENOLOGY



**The field is ready.**

**Harvest as soon as possible.**

**Nothing good can happen after this point.**

## FOREWORD

This is the first version of this document intended for the US sesame farmer. Although I have interacted with many farmers<sup>1</sup> over the past 25 years, it is easy to slip back to research terminology. Comments and new photos are welcome. This is a document for you, the farmer. Please help make it farmer-friendly. This publication is dedicated to my father, Derald G. Langham, who started me crossing sesame when I was 10 years old and ignited a curiosity that still burns within me every time that I walk into a sesame field.

## INTRODUCTION

The purpose of this paper is to describe the development of the sesame crop from seed to harvest in terms of stages. The descriptions are based on current US non-dehiscent varieties. There is a more detailed paper (Langham 2007) that provides descriptions of genotypes throughout the world. This description is based on experience since 1954, with over 38,000 lines of sesame grown in 97 nurseries, and over half a million acres of commercial fields in nine states in the US and ten foreign countries. The lines include 2,953 introductions from 68 countries and crosses between those lines. The observations have been made under conditions varying from irrigated to semi-irrigated to rainfed; from rain in all stages to drought; from low to high fertility; from early to late plantings; from 6 to 40 inch row spacing; from sandy to very heavy clay soils; under all levels of weed infestation; from laser leveled fields to sloping hills; from sea level to over 3,000 ft elevation; in moderate to very high temperatures (120°F); after very high winds (95 MPH), dust storms, hurricanes, lightning strikes, light to heavy hail, frosts, hard freezes, and snow.

Sesame is a survivor crop. For 7,500 years it has been planted by subsistence farmers in areas that will not support the growth of other crops or under very difficult conditions with drought and/or high heat. In some countries, it is grown after the monsoon on

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<sup>1</sup> I have left many footprints in the sesame fields walking next to the following farmers and researchers: Amram Ashri, David Bishop, Tom Blohm, Davey Brooks, Ilhan Cagircan, Agustin and Gianni Calderoni, Steve Chapman, Tedrowe Coulter, Peter Dotray, Joe Hoffman, Leland Falkenberg, Lawrence Friesenhahn, Bruce, Weldon and Rader Gilleland, Ron Goebel, James Grichar, Ray Hancock, Joe Hoffman, Luis Jimenez, Churl Kang, Murray Kinman, Wayne Kreibel, Leon and Rick Leffel, Jim and Randy McElhaney, Jimmie Meeks Sr. and Jr., Gabriel Musa, S.S. Rajan, Jerry Riney, Billy Schwartz, Eddie Schmidt, Clyde and David Sharp, Glenn Smith, Charles Stichler, Mark Wetzel, Terry Wiemers, and Wasana Wongyai. Malcolm Bennett, Alison Dunn, Randy Landgren, and Loretta Serafin provided editorial assistance. My wife, Robyn, and children Jeff, Andy, Alison, and Scott have all planted, crossed, taken notes, and harvested sesame with me and have delighted in finding exceptions to any generalization my father or I set forth.

residual moisture with no rains during its production cycle. In other countries, it is grown in the monsoon season and subject to daily rains during parts of its cycle. In several countries, it is the last crop that can be grown at the edge of deserts, where no other crops grow. Very little sesame is grown under high input conditions, although yields improve dramatically as inputs increase. In the US, sesame has been grown in Arizona under high inputs and in Texas/Oklahoma under low inputs, with all levels of inputs in between.

## THE GOAL = THE SEED

In the US, the seed (Photo 1) is primarily used on top of breads and crackers; however, it is increasingly being used as an ingredient. In the Orient, where most of the sesame is grown and consumed, sesame is primarily a source of vegetable oil. In the Near East, sesame is ground into a paste known as tahini and is consumed in humus.



Photo 1. The purpose of this document is to understand the growth and development of sesame to enable fully mechanized growing of the crop in order to deliver hundreds of truckloads of sesame to the US market. Photo by J. Riney.<sup>2</sup>

Most of the sesame traded in the world is light seeded, but seed coats of local cultivars can vary from white to buff to tan to gold to brown to reddish to gray to black (Photo 2). In the US, the seed on top of buns has been decorticated (removed the seed coat) and thus, appear “whiter” than in the combine. To date, there has not been much trading based on seed contents, but some markets are becoming conscious of the components. Some of the variations in the seed are as follows: hundred seed weight 0.11 to 0.46 g, oil from 34.4 to 59.8%, oleic acid from 32.7 to

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<sup>2</sup> Unless otherwise noted, all photos by D. Ray Langham

58.2%, linoleic acid 27.3 to 59.0%, and protein from 19 to 30%. One of the unique aspects of sesame protein is the high content of methionine. Sesame is also very rich in oil and water soluble antioxidants: sesamin, sesamol, sesamolin, and sesaminol glucosides.



Photo 2. There are many sizes and colors of seeds. Most of the sesame in the US market is medium sized and has a buff color.

## PHASES OF THE PHENOLOGY

There are four phases in the phenology: vegetative, reproductive, ripening, and drying. All but the ripening phase is divided into stages based on growth events that can be seen by the farmer and by key actions that farmers need to make in each stage. Each stage will be described in the following sections: definition, time from planting of the stage, length of time within the stage, description, factors that shorten and/or lengthen the stage, and farmer keys.

There is a tremendous amount of variability in the vegetative, reproductive, ripening, and drying phases of sesame. Sesame is an indeterminate species, and thus, there is an overlap between the reproductive, ripening, and drying phases. Table 1 shows the ranges for lines with commercial potential in the US. To date, very early lines do not provide adequate potential yield, and very late lines have a production cycle that extends into a bad harvest window, which can reduce actual yields substantially and degrade the quality of the seed.

Phase	Days from planting		Length of phase, days	
	Range	Mean	Range	Mean
Vegetative	33-53	40	33-53	40
Reproductive	56-114	81	27-52	38
Ripening	86-121	103	9-34	21
Drying	110-163	144	11-57	43

Table 1. Range and mean of number of days in phases for commercially suitable lines in the US. Most current varieties are close to the mean.

## FACTORS THAT AFFECT PHASES AND STAGES

### Populations

In the US, all commercial sesame is planted mechanically and not thinned. The observations in this paper are based on unthinned stands ranging from very high (23 plants/ft<sup>2</sup>) to very low populations (0.1 plant/ft<sup>2</sup>). In the US, commercial fields are planted with planters ranging from row planters to drills. Farmers have planted from 1.5 to 8 lb/ac of seed (219,000 to 1,168,000 seeds/ac). Farmers who do a lot of tillage work to prepare a good seed bed, have relatively uniform soils, plant small fields, drive slowly, and continually check/modify the placement of the seed, can get a good stand with low planting rates. These farmers plant about 1.5 to 2.5 lb/ac. However, many farmers are reducing tractor passes across the field, do not have uniform soils, plant large fields, drive faster, and do not have time to continually check/modify the placement of the seed. These farmers plant about 3 to 5 lb/ac. Drills are very imprecise (even modern drills with good depth control), and those planters end up planting between 5 to 8 lb/ac.

In addition to the land preparation and planting practices, the germinating seedlings may face environmental factors, such as rain, that may create crusts before emergence, a sudden cold front that may reduce the growth rate before emergence, winds that may blow sand and damage or cover them, insects at the seedling stage, etc. Additional seed is a form of insurance for a good stand because there is no agronomic practice that can improve a poor stand other than replant. The author has been planting 10+ ac nurseries in mid-May to early June on the same farm in Uvalde, TX, since 1988 with the same planter and the same planting rate (about 1.5 lb/ac). In that time, the populations have averaged from 3.8 to 9.4 plants per linear foot. The environment from the emergence through the juvenile stage is more important for final plant number than the seeding rate.

The population density affects the phenotype and the length of time of the phases and stages. As the plants compete for light, high populations grow taller faster than low populations. However, unless there is considerable moisture and fertility, the final height is usually lower in high populations. Given the same moisture and fertility, high populations will use up the resources sooner and will go through the whole cycle faster from the mid bloom to the late drydown stage. High populations will lose lower leaves faster since the light will not



penetrate the canopy. Since populations across a field often are not uniform, there will be some areas ready to combine sooner than others.

In moderate to high populations, there will be dominant plants and minor plants (Photo 3). The dominant plants generally emerge faster and since early growth is a geometric progression, they end up with larger cotyledons leading to larger leaves and deeper roots. These dominant plants will begin shading the other plants which will end up shorter with lower production. Compared to the dominant plants, the minor plants will start flowering later, will stop flowering sooner, and will dry down sooner. Most of the data in this paper is based on the dominant plants.



Photo 3. The seedlings that emerge first will accelerate faster, and the leaves will start covering the later emerged seedlings depriving them of light. This will also lead to less root mass in the competition for the moisture. The larger plants will become "dominant plants" and the smaller ones "minor plants." Photo by A. Calderoni.

The author has found little difference in the yields of populations between 40,500-105,200 pl/ac (3-8 plants/ft) with lines that adjust to the population, i.e., produce more branches in low populations. When the stands are uniform, even lower populations plants can provide equal yields, and when there is adequate moisture and fertility, much higher populations can still yield well. One positive aspect of a higher population is that it forces the sesame to grow faster and shade out competing weeds. In Texas, Kinman and Martin (1954) found little difference in yield between 10,100-198,300 pl/ac because of high stand tolerance. In Australia, Bennett (1998) strived for 121,400-141,600 pl/ac and Sapin et al. (2000) recommended 80,900 to 161,900 pl/ac. In Venezuela, Avila (1999) found little difference between 121,400-141,600 pl/ac.

### Moisture and fertility

Throughout this paper there will be references to irrigated and rainfed, which are relative terms. Rainfed fields near Oklahoma City have more available moisture than irrigated fields in West Texas, where some farmers irrigate but rarely with more than 1-2" of

water. In the main sesame growing areas in the US, the average rainfall ranges from 18-37" and little of the rain (zero to 5") is in the 70 days that are critical to sesame in the reproductive and ripening phases. Rain that falls on a full moisture profile does not help; rain that falls in the first 30 days often will set back the plants more than it helps them; rain after the seed is filled does not help. In these areas, summer rains are often in the form of strong thunderstorms that can have 1" of rain in one part of the farm and zero rain a quarter mile away. These same storm cells can drop 2" per hour and much of the moisture can run off the field instead of penetrating the soil. It is not unusual for storms to rain 8-16" in one spot in 24 hours. The number of days in each phase of the phenology depends on the amount of moisture available to the crop.

Sesame is drought tolerant, but as with every crop, sesame will do better with more moisture. There have been many cases where sesame has done well in fields with low to no fertility, but after coming back to the same field the following year, the sesame did not do as well. In analyzing the cropping history of that field, it was found the previous crops were shallow rooted, and it is hypothesized that the sesame roots went down and found fertility that had leached deeper into the soil.

There are two types of sesame: those used in dry areas or seasons and those used in high moisture or seasons. Generally, wet sesame does not do well in dry areas but dry sesame may do well in wet areas. The dry lines generally have a strong root that will penetrate deep into the soil to stay in the moisture. The wet lines generally root shallower. There are intermediate lines that are productive in wet or dry but will not do well in the extremes.

Within a line, there are two basic architectures with many gradations in between: high input and low input architectures. The high input architecture occurs when there are good moisture and fertility during the vegetative and reproductive phases. The leaves are larger and the internodes longer, resulting in a higher height to the first capsule, more capsule node pairs, and taller plants. The low input architecture occurs when there is low moisture and/or fertility. The leaves are smaller, the internodes shorter, lower height of the first capsule, fewer capsule node pairs, shorter plants, shorter capsules, fewer seeds per capsule, lower hundred seed weight, and lower seed weight per capsule. To illustrate the effect, Fig. 1 shows the variation within S26

grown under 6 environments. The relative size of the leaves is the best visual cue as to the amount of moisture and/or fertility with higher levels producing larger leaves.

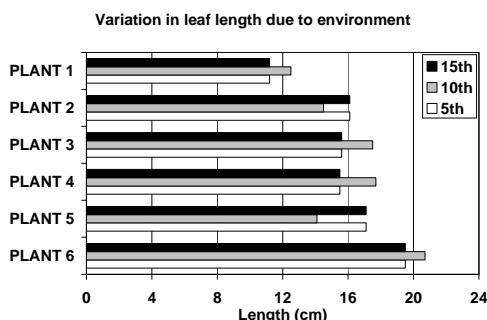


Fig. 1. Variation of leaf length in S26 based on the environment. The measurements are made at the 5<sup>th</sup>, 10<sup>th</sup>, and 15<sup>th</sup> node pairs. Plant number 1 has had the least water and fertility and plant 6 has had the most.

If the plants start in high input mode and do not get the appropriate moisture in a timely fashion, the plants will drop the lower leaves and newer leaves will be smaller with shorter internodes, in essence, converting to a low input architecture. During this conversion, the lower leaves will drop until enough leaf surface has been shed to equalize the transpiration to the available moisture. In some cases, applying an irrigation too late after the conversion can actually damage the crop by placing too much stress on the plants. Although a drought can reduce yield considerably, in the US, sesame will survive a drought and make viable seed.

If a crop begins in or converts to low input architecture, it will not change to a high input architecture no matter how much moisture and fertility becomes available. However, the plants will continue putting on flowers and capsules despite the small leaves at the top of the plant. The final height of the plant is influenced more by the vegetative phase than the reproductive phase. Some high input crops look like they will be very high yielding because the plants are so luxurious, but the plants may not yield as well if the high inputs are used in the vegetative stage and there is not enough moisture and fertility at the end to make good seed fill.

The interrelationship between moisture and fertility is very evident. If there is adequate moisture and low fertility or if there is little moisture and adequate fertility, the yields will not be good. However, in the intermediate range, it is not known whether moisture or fertility is more important.

## Phenotypes

Phenotypes are categorized in terms of branching style, number of capsules per leaf axil, and maturity class. Branching is the first character with the following values: unicum (1), few (4), or many (7).

Capsules per leaf axil is the second character with the following values: single (1) or triple (3). Maturity class is the third character and is in terms of days from planting until physiological maturity. The values are very early (V - fewer than 85 days), early (E - 85 to 94 days), medium (M - 95 to 104 days), late (L - 105 to 114 days) and very late (T - more than 114 days). Within Sesaco, there is no selection for very early or very late lines as shown in Table 2.

	Single capsule per leaf axil		
	Unicum	Few branches	Many branches
<b>Late</b>	S11 S22		S04 S05 S12 S16
<b>Medium</b>	<b>S30</b>	S01 S08 S09 S24 S27	S20 <b>S26</b> <b>S28 S32</b>
<b>Early</b>		S07 <b>S25 S29</b>	

	Triple capsule per leaf axil		
	Unicum	Few branches	Many branches
<b>Late</b>	S06 S15 S50 S51		
<b>Medium</b>	S02 S10 S17 S19 S21	S14	
<b>Early</b>	S52	S03 S23	

Table 2. Phenotypic distribution of Sesaco varieties. Current varieties are in bold and underlined. A large range of phenotypes has been developed because different environments (frost-free days, temperatures, rainfall patterns, farmer equipment, and farmer practices) favor different phenotypes.

New varieties are chosen primarily by yield. Under the growing conditions in Texas and Oklahoma in wide row spacing, branched single capsule lines have the highest yields. In closer row spacing (<30"), single stem/single capsule lines have had the highest yields.

## Branching

There are lines that have no branches (unicum) and lines that have branches (Photo 4). Branching generally takes place in nodes on the bottom of the plant below the capsule zone. The amount of branching is scored as 'few' and 'many' based on general behavior of the lines in different populations and row spacing and by observing the ratio of the number of nodes to the first capsule to the total number of nodes on the main stem. In normal populations, 'few branch' lines will have 2-4 branches, and 'many branch' lines have 6 or more. 'Many branch' lines have more nodes below the first capsule and will have fewer nodes on the main stem. Having defined the difference



between few and many, the definition is difficult to apply because the amount of branching varies with different growing conditions. In wide row spacing with intense light, a 'few branch' line will have 6 or more branches, and under low fertility and moisture, a 'many branch' line will have 4 branches or less.



Photo 4. Plants on the left are unicum (no branches) and on the right are branched. Photo by W. Wongyai.

Direct sunlight has a tremendous effect on the amount of branching. In order for a branch to form, light needs to strike the leaf axil. In some unicum lines, there is no branching at all under all circumstances. However, most unicum and branched lines have the potential to branch in every leaf axil. Some lines have the potential to form secondary branches on the branches, and a few have the potential for tertiary branches. In some lines, if there is sunshine at the second pair of leaf axils of a branch, another branch will form, but in lower light, a capsule will form. In order for a branch to continue growing, it needs light at the tip. The amount of light that reaches the branches is dependent on population and/or leaf area. Higher populations and more leaf area shade the leaf axils.

Latitude and row spacing can affect branching. With wider row spacing, more light gets to the lower part of the plant. In northern latitudes, there are longer days in the summers providing more light. In the US, areas like Lubbock, TX, with northern latitude and wider row spacing, have the most branching. Areas with less clouding have more branching, as direct sunlight has more effect than weak sunlight.

### Capsules per leaf axil

Capsules form from flowers in the leaf axil on the 4<sup>th</sup> to 6<sup>th</sup> node pairs and continue to the top of the plant (Photo 5). Each node may have single or triple capsules (Photo 6). Some farmers remember the old Sesaco varieties that had triple capsules, and occasionally, there is a triple capsule outcross in the

present varieties. Upon seeing these, farmers comment that varieties should be developed with triple capsules.



Photo 5. Farmers familiar with cotton count by leaves, and soybean farmers count by node. US sesame varieties have opposite leaves that develop at basically the same time, and thus, sesame is counted by node pairs. The yellow on each side of the capsule is a nectary, which is a rudimentary flower. In high light conditions, it can develop into a flower and then capsule. Photo by A. Weisker.

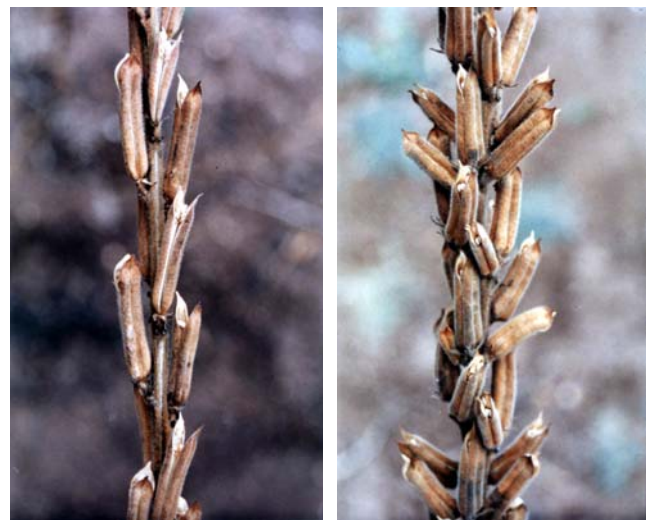


Photo 6. Plant to the left has single capsule per leaf axil and to the right triple capsules. These are non-dehiscent capsules that will be described in the drying phase.

Most triple capsule lines have single capsules at the bottom and top of the plant and rarely have three capsules in every node. Axillary capsules on triple capsule lines are rarely the size of the central capsules and have fewer seeds with lower seed weight, resulting in lower seed weight per capsule. In a 1999 Sesaco study, the axillary capsules averaged 79.4% of the weight of the central capsule. The axillary capsules also have less shatter resistance, and thus, they lose more

seed while drying down. In the wind, leaves act like shock absorbers as the plants rub against each other, and when the leaves drop, the triple capsules rub off much easier than the single capsules. Ultimately in the US, single capsule lines have more yield in the combine bin than triple capsule lines. Since all of the present Sesaco varieties are single capsule, the document will emphasize single line growth and development.

### **Maturity class**

As mentioned, maturity is broken into 5 classes, very early, early, medium, late, and very late (Photo 7). The maturity class is the sum of the first three phases: vegetative, reproductive, and ripening. The drying phase is not used because it is the one that is affected the most by the environment. As mentioned before, the very early lines do not have enough potential yield and the very late lines mature in late fall/early winter when the harvest weather deteriorates. The effects of moisture, fertility, temperatures and other weather conditions on maturity class will be discussed in each stage.



Photo 5. Plants to the left are early lines in the late bloom stage; plants in the middle are late lines in the pre-reproductive stage; and plants to the right are medium lines in the mid bloom stage. With a few exceptions, there is a high correlation between larger leaves and later sesame.

### **Plant color**

Lines have different shades of leaf color throughout the growing cycle. During the vegetative and reproductive phases, the color is usually a shade of green; and then as the plants mature and begin to drop their leaves, the color will turn to many shades of yellow/green and rarely purple. There are many lines that have purple on the upper surface of the petioles. The purple on the leaves, stems, and capsules can appear anywhere from late bloom stage until the drying phase. The color of the leaves usually matches the color of the stem and capsules. Within a line the

shade of color is an indication of what is happening with the plant.

- Generally, when the plant is in normal growth, it will be one shade of green. In two side-by-side fields with the same variety, the darker green will generally indicate better fertility.
- If a field starts getting a very dark green with almost a bluish hue, it is running out of moisture. When there is a rain or irrigation, there will be a growth spurt leading to a lighter green.
- If there has been a lot of rain, the field may turn yellowish green indicating that the roots are not getting adequate oxygen. With aeration from cultivation, the leaves can green up within a matter of 6 hours. The greening up from the soil drying out, without a cultivation, takes a longer time.
- When the plants start to drop their leaves and turn yellow, the shades of yellow are an indication of moisture and/or fertility at the end of the cycle. If the leaves turn a pale yellow and stay on the plant, it is an indication that the plants ran out of fertility. If the leaves turn a darker yellow and most of the leaves drop earlier than normal, it is an indication that the plants ran out of moisture.

### **Roots**

Very little research has been done on sesame roots, but they are very important to the phenology. Generally, sesame plants have a strong tap root component and some fibrous roots (Photo 8). However, under differing conditions, the plants may have a stronger tap root or a stronger group of fibrous roots.



Photo 8. The root is a mixture of tap and fibrous roots. In this root, the tip was stopped by a rock but then found a way around the rock, and the tip of the tap root is broken off at the top. In Yuma, AZ, roots were followed 8 ft deep until they were lost. Photo by A. Calderoni.

Sesame is considered a drought resistant species because the root will penetrate deep into the soil to find moisture. However, every crop needs moisture, and in a year with little deep moisture, sesame will not do as well. In the US, the optimum situation is to plant sesame into moisture and have no added moisture for about 30 days. Under these conditions, the roots will follow the moisture down, and sesame can withstand a lack of rain for the rest of the cycle. If there are rains or irrigations soon after planting, there will be more fibrous root development in the upper 12" of soil with shorter tap roots. If this condition is followed by a drought, the plants can be in trouble as the moisture in the top 12" is depleted, or a heavy rain can waterlog the plants and kill them.

Weiss (2000) cites Lea (1961) that in clay soils of Sudan, roots penetrate 10" in ten days, 20" in 24 days, and 30" in 50 days. Weiss states that roots will penetrate faster in sandy soils and grow more profusely; late flowering lines have deeper roots. Root growth is inhibited by salt concentrations lower than most crops. The author has found a rough correlation between unicum stems and single tap roots and between branched stems and branched tap roots. However, there are many exceptions in both directions.

Generally, the roots are as deep as the plants are tall. By the end of the reproductive phase, most of the moisture is being drawn out of the 3-4' layer of soil. In Yuma, Arizona (AZ), in 1983, the Soil Conservation Service placed neutron probes in sesame fields and found the deep moisture depleted while the surface of the soil was almost muddy.

### Time of planting

The time of planting can have a major effect on the final size of the plants and the yield. J.R. Mulkey et al. (1987) and the author have carried out four 'time of planting' studies in Uvalde as shown in Fig. 2.

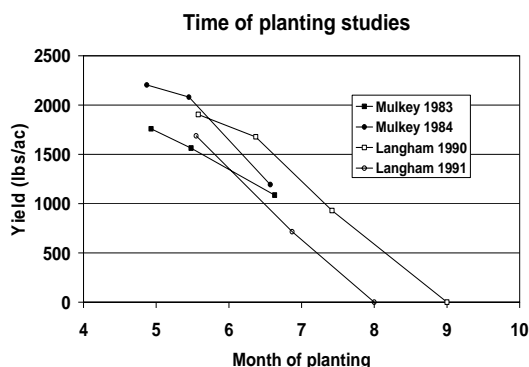


Fig. 2. Effects of dates of planting on yield in Uvalde, TX. There is a very high correlation between the number of daylight hours during the first three phases of sesame and the yield. June 21 is the longest day of the year, and sesame planted at the end of

April or early May gets the most daylight.

Late April and early May are the optimum time to plant in the northern hemisphere. However, as will be shown later, the soil temperature must be sufficiently high at planting to germinate the seeds. Planting in April is risky because the soil temperatures may be too low, and the one farmer that was able to get a stand in March had a very poor yield. The data clearly shows that the yields decrease the later the crop is planted. In the other sesame growing areas of the US, it is difficult to plant at this time because the soil temperatures are still too cool. However, in every area, the earliest planted generally has the highest yield.

There is a very high correlation ( $R=0.864$ ) between yield and accumulated daylight hours as shown in Fig. 3. The number of hours of daylight for the first 100 days (*vegetative phase* through *ripening phase*) was summed for each planting date beginning on April 1 and ending on Aug 1. With June 21 being the longest day of the year, the peak occurs around May 1. Note that the further north that the crop is planted, the higher the number of daylight hours, which accounts for the ability to have high yields further north where the crop is planted around June 1.

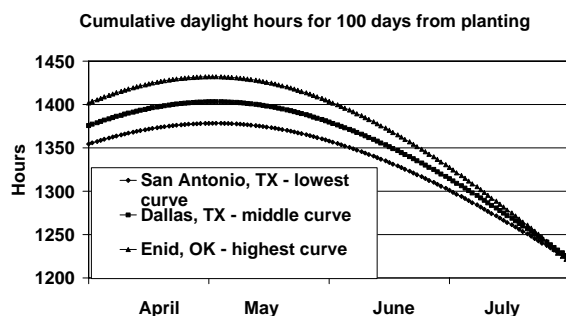


Fig. 3. The yields are highly correlated to the number of daylight hours in the first 100 days after planting. The best time for planting in all areas May 1, but the ground temperatures are too cool in the northern sesame areas. However, longer daylight hours somewhat compensate for this.

In Table 3 in Sudan, Tanzania, India, and Korea (Weiss 2000), Korea with two systems of planting (Lee 1986), and Ciudad Obregon, Mexico (G.C. Musa 1988, pers. commun.), 'time of planting' studies show the same pattern: planting in late April and early May results in the highest yields. In the environments similar latitudes as the growing areas in the US (Mexico, India, and Korea), the data shows that planting earlier (March and early April) or later (June and July) results in lower yields.



Author	Country	Planting date	Yield (kg/ha)
Weiss	Sudan	Mid-June	1096
		Mid-July	346
		Mid-August	293
	Tanzania	Mid-Jan	973
		Mid-Feb	835
		Mid-Mar	521
	India (Bengal)	Mid-May	325
		Mid-June	101
		Mid-July	45
	Korea	Mid-Apr	677
Mid-May		764	
Mid-June		437	
Musa	Mexico	10-Apr	765
		20-Apr	885
		10-May	985
		30-May	766
		20-Jun	408
		10-Jul	285
Lee	Korea (Conventional)	1-May	670
		15-May	540
		25-May	480
		15-Jun	370
		25-Jul	50
	(Vinyl mulch <sup>2</sup> )	1-May	1270
		15-May	1110
		25-May	670
15-Jun		500	
	25-Jul	101	

Table 3. Effects on time of planting on yield in diverse environments. For the US sesame latitudes, the pattern is consistent – planting in April has lower yields, but from May on the yields also decrease. In Korea, farmers plant under vinyl in order to heat the ground temperature and allow for earlier planting.

## RATE OF GROWTH OF IRRIGATED SESAME

Fig. 4 shows the rate of growth of three varieties under irrigation in 2004 in Uvalde and shows how in the first 34 days, the plants reach about 1 foot in height and yet will double to 2 ft in the next 11 days, triple to 3 ft in the following 8 days, and quadruple to 4 ft in the following 9 days. At this point, the sesame will begin to canopy and the rate of growth will level off. In rainfed conditions, the final plant heights are lower, but the pattern of very slow growth followed by fast growth during the reproductive phase exists under all conditions.

Sesame grows slowly in the beginning because it is using its resources to put down the root that is following the moisture. In seeing that the internodes shorten from bottom to top, there has been a misconception that once flowering begins, the rate of growth slows down. As can be seen in the figure above, the rate is fairly constant from the start to end of flowering.

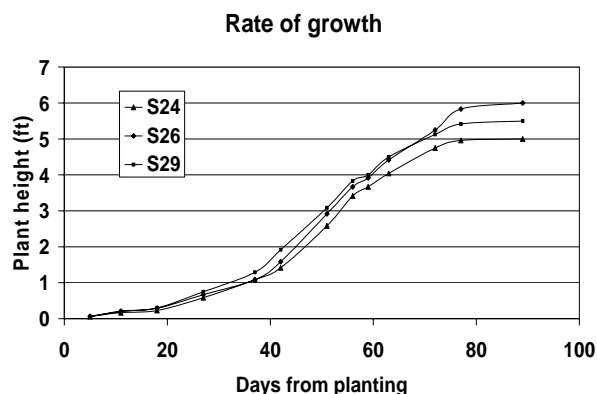


Fig. 4. Rate of growth of 3 US varieties in adjacent plots. It takes 34 days for the plants to reach 1 ft in height, will reach 2 ft in the next 11 days, 3 ft in the next 8 days, and 4 ft in the next 9 days. It basically is 1 ft in 34 days and quadruples to 4 ft in the next 28 days.

## BASIS FOR NUMBER OF DAYS TO AND WITHIN PHASES/STAGES

The description of each stage provides the number of days in terms of S26 planted in Uvalde in 2004. S26 is used as the example because it has been the major variety planted in this time period, and thus, there is much more commercial experience. Any one variety will be different, depending on the growing conditions for that field and the weather for that year. The timing of the rains can have as much an effect as the quantity of the rains. For example, a rain at 30 days from planting for one field can help that field, while an adjacent field just planted may get crusted in and not be able to emerge.

Table 4 and Fig. 4 to 7 show data on S26 from 2000 to 2006. The 2003 nursery is not included because it was damaged by hail in the juvenile stage and by the eye of a hurricane in the mid bloom stage. The hail destroyed 30% of the leaf surface, and the hurricane leaned the crop over but did not lodge it. These nurseries were planted within 500 yards of each other on the same soils, using the same planter, and under irrigation. Moisture (amount and timing) and fertility make a tremendous difference in production.

In 2000, there was a rain substituting for the first post-plant irrigation that prevented adding the application of the post-plant nitrogen, which terminated the crop earlier. Then, there was no rain from the end of flowering to drydown, which accelerated complete drydown. In 2001 to 2005, there were rains between ripening and drying, lengthening this period.

	2000	2001	2002	2004	2005	2006
Planting date	05/28	06/06	06/09	05/17	05/20	05/25
Previous winter crop	Wheat	Wheat	Wheat	Fallow	Fallow	Fallow
Pre-plant nitrogen (lb/ac)	30	30	30	30	30	30
Method of irrigation	Furrow	Furrow	Furrow	Furrow	Furrow	Pivot
No. of Pre-plant irrigations	1	1	1	1	1	1
Post-plant nitrogen (lb/ac)	0	30	30	30	30	30
No. of post-plant irrigations	2	2	2	3	3	3
Yield sampling (lb/ac)	1,293	1,543	1,494	1,540	1,645	1,485
Branching style	Many	Many	Many	Many	Many	Many
No. of capsules/leaf axil	1	1	1	1	1	1
Days to flowering	41	40	42	44	43	42
Days to flower termination	79	75	81	90	89	79
Days to physiological maturity	96	103	102	106	106	97
Days to direct harvest	114	154	145	146	141	118
Height of plant (in)	50	56	65	69	64	61
Height of first capsule (in)	20	19	24	25	22	26
Capsule zone length (in)	30	37	41	43	42	35
No. of node pairs on main stem	23	29	29	31	30	27
Internode length (in)	1.3	1.3	1.4	1.4	1.4	1.4
Capsule length (in)	0.9	0.9	0.9	0.9	0.9	0.9
Seed wt per capsule (g)	0.219	0.254	0.234	0.280	0.239	0.243
Hundred seed wt (g)	0.326	0.328	0.337	0.352	0.344	0.310

Table 4. Data on S26 between 2000 and 2006 planted in research nurseries in Uvalde, TX. The same variety planted in multiple years in the same location can vary widely based on the environment. In 2006, there was a total of 5" of irrigation with only 10% of the average rain the previous 12 months.

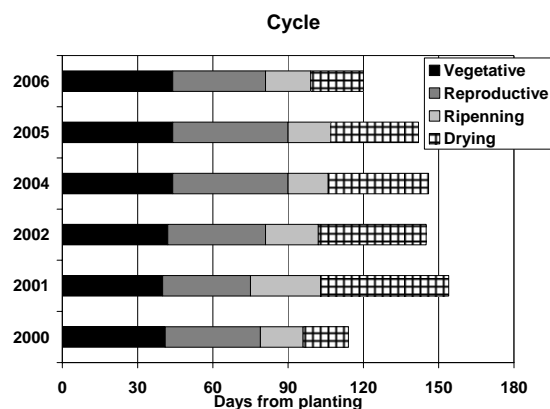


Fig. 5. In dry years of 2000 and 2006, the cycles are much shorter. The drying cycle can be extended with rain at the end as in 2001.

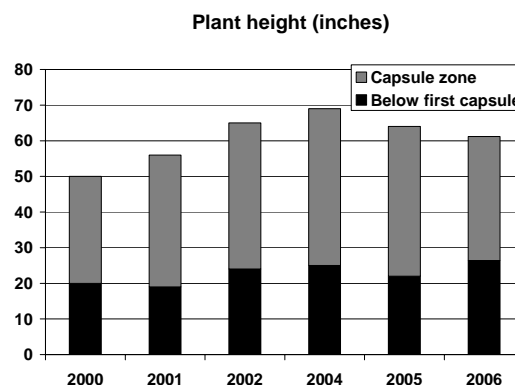


Fig. 6. In 2000 the second fertilizer was not added, resulting in shorter plants. With rain in the vegetative cycle, the plants will generally be taller as in 2004.

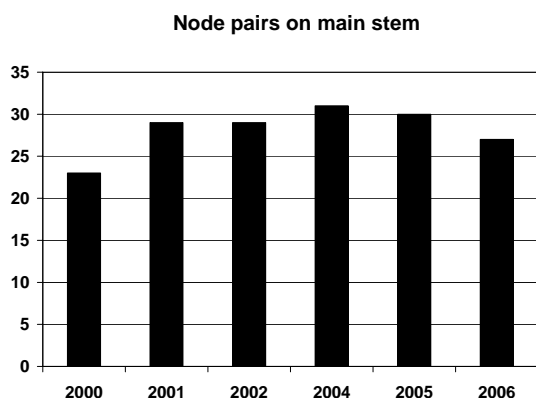


Fig. 7. The number of nodes on the main stem are correlated to the amount of moisture with dryer years having less nodes, as in 2000 and 2006.

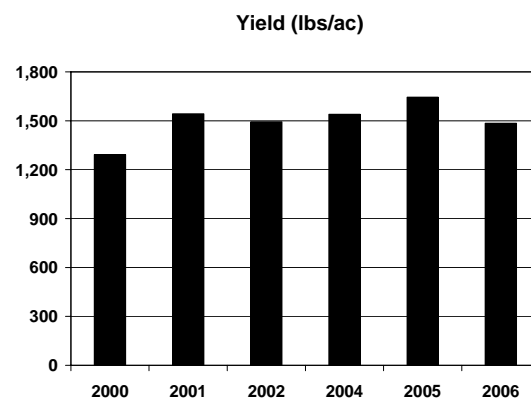


Fig 8. The lowest yield was in the dry year of 2000 when a second shot of fertilizer was not applied. In all other years, there was little statistical difference between yields despite differences in number and timings of rains.

## **Farmer keys before the crop is planted that affect the phenology**

In reading this document from front to back, certain farmer keys are repeated. Some farmers refer to the current stage of their crop, and if a key point applies to more than one stage, it is repeated.

### *Soil preparation and planting*

Soil preparation should be such that there is a fine textured seed bed. Uneven depth of moisture and clods can lead to irregular germination. The plants in a low population behave differently with much more emphasis on branching and a longer cycle. In the end, the low population areas stay greener and delay harvest, while the high population areas dry down faster and may be subjected to weather that leads to more shattering.

Sesame should be planted into the moisture with a dry cover over the top. The better the moisture, the faster the seeds will absorb moisture and germinate. If the moisture is too dry for cotton, it will be too dry for sesame.

### *Irrigations*

Pre-irrigations or rains are the most important water the crop will receive. With a strong root system that will follow moisture down to as much as 6-8 feet, sesame is a drought tolerant crop. The pre-irrigation should be heavy with stacking up the water at the ends, if possible. When there is a full soil moisture profile, the plants go through less stress.

After planting, borders at the end of the field should be leveled so that water does not stack up at the end of the field. Too much water can slow down development or even kill sesame.

### *Fertility*

One of the dilemmas that a rainfed or semi-irrigated farmer faces is the amount of fertility to add. In order to optimize both yield and net return, the amount of fertility added should be commensurate to the amount of moisture; however, it is impossible to know if the summer will be dry or wet.

The sesame roots penetrate the soil deeper than most crops, and thus, they reach a reservoir of fertility that has not been used. There have been many cases where farmers plant sesame with no fertility and get a good crop because of that deep fertility. However, once that fertility is mined, it is no longer available for the next sesame crop, and the yields drop off substantially without fertility.

Most vegetable crops get pushed with fertility that the crop does not use, leaving plenty for sesame. Some pre-plant fertility will allow the sesame to develop quickly and get to the reservoir of fertility

that was left below the root zone of the vegetable crop.

On the other hand, there are farmers planting after wheat that do not add fertility to sesame because they added a lot of nitrogen to the wheat late. Although all of the fertility may not have been used, when the wheat is disked in, the straw ties up the nitrogen through the critical first 30 days of growth.

Although soil sampling is a very important agronomic practice, most samples use only the top foot of soil. Knowledge of previous crops on that field, amounts of nitrogen the crops pull out of the soil, and fertility practices should be used in conjunction with sampling.

Sesame seed contains about 25% protein, and it is estimated that 1,000 lbs of sesame seed contains 18 to 21 lbs of N. The plants (without the seed) on a 1,000 lbs/ac crop will have about 30 lbs of N, which will go back into the soil at harvest.

If at all possible, fertility should be split up with half as a pre-plant and the rest during the late vegetative or early reproductive phases. Having all of the fertility up front will produce large plants with luxuriant leaves, but the seed production will not be as high as the plants promise the eye of the farmer.

The type of N is important. Slow release N formulations are good for pre-plant but may not be effective in later applications if it is dry. Many fertilizers require microbial action to make the N available to the plant. In dry conditions, the nitrogen is not available.

## **VEGETATIVE PHASE**

The vegetative phase is divided into four stages: germination, seedling, juvenile, and pre-reproductive.

### **Germination stage**

*Definition:* From the time the seed meets moisture (Photo 9), until most of the seedlings emerge from the soil. In the US, most sesame is planted into the moisture, but there are a few cases where the seed is planted in dry soil and then watered up.

*Time from planting:* 3-5 days. For seed planted about 1" deep in good moisture, in South Texas, the low end is usually 4-5 days in late April and 3-4 days planted in mid May. In northern Texas and Oklahoma, the low end is 4-5 when days planted in late May and 3-4 days if planted in late June.

*Description:* Germination is one of the most important stages because if there is a poor stand,



no subsequent farmer action or weather condition can produce a high yield. The threshold temperature for sesame is 61°F (Angus et al., 1980). In the early years of US commercial production, the recommended minimum planting temperature was 75°F (Kinman 1955). Weiss (1971) states that should temperatures fall below 68°F for any length of time, germination may be inhibited and will certainly be delayed. In planting hundreds of thousands of acres of sesame since the 1980s, the current recommended minimum temperature is 70°F (Langham et al., 2008). This does not mean that sesame will not germinate at a lower temperature. The recommended temperature is based on a reasonable probability of achieving a full stand. Higher temperatures increase the rate of germination and increase the probability of achieving a full stand.



Photo 9. Seeds are planted into the moisture and then covered with dry soil. Photo by A. Calderoni.

Temperatures between 77-81°F encourage a rapid germination, initial growth, and flower formation (Weiss 1971). The author has found that with soil temperatures around 77 °F, the seed imbibes enough moisture that it is soft within 24 hours, and the seed can be pushed out of the seed coat with a bulge at the tip of the seed. Between 24 and 48 hours, the radicle emerges and within 12 hours of emerging, the root will push down and start following the moisture. Between 36 and 60 hours, the seedling will start pushing up through the soil. Between 3 and 5 days, the seedling emerges from the soil. In raising the soil temperature to 84°F, the radicle can be as much as a third of an inch long and pushing down in 24 hours.

#### *Factors that shorten stage:*

- Shallower planting (however if too shallow, may lose moisture and not germinate).

- Reduced soil compaction (however, some soil types lose moisture quickly under no compaction).
- Higher seeding rates (sesame has small seeds, and more seeds together have more push).
- Higher temperatures.

#### *Factors that lengthen stage:*

- The inverse of the above: deeper planting, increased soil compaction, lower seeding rates, and lower temperatures.
- There are some root pruning herbicides, such as pendimethalin and trifluralin, that also lengthen the stage.

#### *Germination farmer keys:*

- Soil temperatures need to be 70°F at planting depth at 7 AM. Rule of thumb: if you feel you need a jacket, it is too cold to plant sesame.
- Understand that the soil temperatures go up and down sharply each day as shown in Fig. 9.

**Soil and air temperature daily variation**

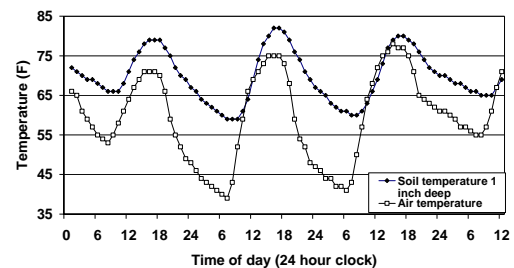


Fig. 9. Air and soil temperature at Batesville, TX, 1-4 April, 2005.

- The germination stage is very vulnerable to rain, which can create a crust in the soil over the sesame (Photos 10-12). If the seedlings are caught in the crust, there is no hope and the sesame should be replanted. If the seedlings are below the crust, there is a possibility that the crust will crack and allow the seedlings to emerge.
- The ability to break through a crust is dependent on the thickness. In areas where soil “bakes”, sesame can push through very thin crusts but will not break through the type of crusts that cotton or other large seeded crops can break through.
- Final stand should be judged at 7 days after planting. Although more seed may come up after that time, there will rarely be enough to change a marginal stand to an acceptable stand.



Photo 10. These seedlings are emerging within a crack. They had been planted 1" deep 70 hours before with soil temperatures around 77°F and then had a 0.3" rain about 60 hours after planting. The sun created cracks along the seed line. These seedlings will be in danger until the seedlings are above the crack if there is rain that closes the cracks, or wind that blows sand covering the crack.



Photo 11. This had been planted 96 hours before and then had two 0.3" rains. In the top photo, there is some evidence of the seedlings pushing up the crust, but no seedling has found the crack. In the photo below, removing the crust shows several seedlings pushing.



Photo 12. The crust was removed from photo 9 (note the crack pattern in the lower right corner). Several seedlings can be seen right below the surface. The seedlings to the right and left were above the surface the next day.

## Seedling stage

*Definition:* From seedling emergence point until the third set of true leaves is the same length as the second set of true leaves.

*Time from planting:* From about 6 days to 25 days.

*Length of time:* About three weeks.

*Description:* When the seedlings first emerge (Photo 13), the cotyledons are yellow and inverted in a crook. Within several hours, the cotyledons straighten up, open and the shoot primordia start growing. This is the stage where the plants will start differentiating in size. Depending on the temperature at planting, the amount and size of clods in the field, and the population, the stand can be seen from the edge of the field, 7-12 days after planting (Photo 14).



Photo 13. Cotyledons emerging. The green seedlings emerged the day before, the yellowish seedlings are emerging, and some have still not flipped up.

The first seedlings that emerge will normally have the largest cotyledons and will accelerate their growth the fastest. This will lead to larger leaves and longer roots. The plants with longer roots will compete against the later emerged plants by pulling more moisture and fertility. The larger leaves have an effect in a high stand in that they will begin to shade the later emerged plants and reduce the amount of light they receive. The larger plants will become dominant plants and will form the canopy. The minor plants will be below the canopy.

Depending on variety, some minor plants will turn to the weaker light in the furrows and when they emerge into the sunlight, will turn vertical. They will still be minor plants, but they can be productive. In other varieties, the minor plants will stay within the canopy and will produce few



capsules and may die. This later phenomenon is known as self-thinning.

In some cases when there is a weather phenomenon that damages the dominant plants (e.g., hail or lodging), the minor plants will emerge from under the canopy and become the dominant plants. In other cases with limited moisture/fertility, all of the plants will exhaust the available moisture, and the minor plants will be very short and have few capsules.

There are some occasions when all of the seedlings emerge at relatively the same time. In this case, no one seedling has a clear advantage, and this can lead to abnormal growth. This group of plants will compete equally for light, resulting in much taller plants. Similarly, roots will compete equally but will end up shallower than normal as the plants shift their resources to making stems and leaves. This group of plants will eventually be shorter than the rest of the field, as the resources are divided equally with less water and fertility to each plant. This group will also mature and dry down sooner than the rest of the field.



Photo 14. A view of sesame 9 days after planting in June when the soil temperatures are higher and the seedlings grow faster.

The time of day that the seedlings emerge can be a factor. Seedlings that emerge in the evening just before dark, do not have an advantage over seedlings that emerge 12 hours later the next morning. However, because of the sunlight, these morning seedlings will have a clear advantage over the seedlings that emerge 12 hours later. There are some soils that crack allowing light to the seedling before it reaches the surface. These seedlings may turn green and if given enough of a crack, the cotyledons may invert before reaching the surface. These will generally emerge unless they are covered by rain (closing the crack) or by blowing sand.

In 2003, about 1500 acres were planted between May 2 and 29 in Batesville, TX, under pivots. Fig. 10 is based on observations from those fields. Zero denotes cotyledons with no visible true leaves. A leaf pair is counted when it exceeds the length of the previous pair. Up to that point, decimals are used, e.g., 2.5 indicates that the third pair of leaves is 50% the length of the second pair. This system can be used to estimate the number of days since planting in a field.

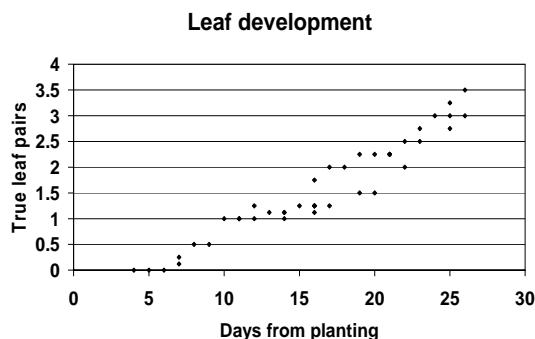


Fig. 10. Rate of development of true leaves on commercial sesame in 2003 in Batesville, TX

Within several days, the 1<sup>st</sup> set of true leaves will be visible but will not equal the size of the cotyledons until about 1 week after emergence (Photo 15). The 2<sup>nd</sup> set of true leaves is visible about 8 days after emergence, and it exceeds the length of the 1<sup>st</sup> leaves in about 13 days (Photo 16). The 3<sup>rd</sup> set of true leaves becomes visible at about the same time and exceeds the length of the 2<sup>nd</sup> about 20 days after emergence. At this point, the plants are about 6" tall. By the time the 3<sup>rd</sup> leaves equal the 2<sup>nd</sup> leaves, the 4<sup>th</sup> set is visible, and then before the 4<sup>th</sup> set equals the 3<sup>rd</sup>, the 5<sup>th</sup> and 6<sup>th</sup> sets are visible. From the 1<sup>st</sup> through the 5<sup>th</sup> or 6<sup>th</sup> leaves, the leaf area will get larger, and then the leaves will generally get smaller all the way to the top of the plant.

#### *Factors that shorten stage:*

- Larger cotyledon size. Within a variety with the same size seeds, the faster the seedlings emerge, the larger the cotyledons because there has been less expenditure of stored materials to emerge. Between varieties, larger seeds have larger cotyledons.
- Higher temperatures.

#### *Factors that lengthen stage:*

- Rain or irrigation that reduces the oxygen available to the roots and compacts the soil. Sesame does better when there is no rain or irrigation until about 30 days after planting as long as there is sufficient moisture (see below).



- Lack of fertility. This is particularly evident in fields that have been planted after a disced in crop where there has been no additional fertilizer and the old crop plant matter is tying up the fertility.

#### *Seedling farmer keys:*

- Sesame seedlings cannot be “wind-shielded.” It takes longer to see the sesame rows from a moving vehicle. You need to get out of the truck to see the seedlings in the first few days. The cotyledons are nowhere near the size of larger seeded crops such as cotton, corn, wheat, peanuts, or soybeans.
- Be patient. The root is growing faster than the stems, and a strong root is the most important part of the plant in dry areas of Texas and Oklahoma.



Photo 15. The seedlings are at the 1<sup>st</sup> set of true leaves as the length is greater than the cotyledons on most seedlings. Although it is preferable to have a fine seed bed, sesame will come up under rough conditions. Photo by A. Weisker.



Photo 16. The seedlings are at the 2<sup>nd</sup> set of true leaves with the third set visible and the cotyledons obscured. Note that the plant on the right is covering a minor plant. Photo by A. Weisker.

- Farmers with irrigation can be very tempted to water during this stage to bring up seed that dried out before it could germinate. There is a trade-off

in terms of cost of irrigation and the amount of yield increase versus decrease. Sesame does not like water at the beginning because it compacts the soil and reduces oxygen to the roots, and there is the potential of making the roots lazy and not penetrating as deep. Shallow rooted sesame will dry out quicker and increase the number of required irrigations. Present varieties are branched and can close in one foot gaps. Yield problems usually start with 2 ft or more gaps, depending on the percentage of the field with the gaps. At some point, it is better to replant than to water back. If the gaps are too great and an irrigation is done, the irrigation should be as quick and with as little water as needed.

- There is one large exception to early irrigations. When planting pivots after wheat, there can be some very dry soil. In putting on moisture to allow a tractor to move an implement across the field, some of this moisture will be lost in the field operation. It is very difficult to fill the lower moisture profile with a pivot, and follow-on irrigations will have to be made to keep the seedling from drying out. This is a vicious circle because the more irrigations that are added, the lazier the roots will become, leading to shallow rooting.
- The seedlings need light to grow. In planting no-till into wheat, if the stubble is not low, the seedlings will emerge into a good stand but will not develop. In a farmer experiment, one half of the wheat stubble was left at about 1 ft and the other half cut to about 4 inches. A week later, both stands looked identical. At 6 weeks, the sesame in the short wheat stubble was over 2 ft tall, while the sesame in the tall stubble was still less than 6 inches tall. The latter half was never harvested because it was producing less than the cost of the cutting.
- With the right speed and cultivator set-up, sesame can be cultivated, but the plants are still too small to throw up dirt on the stems.
- The grass control herbicides fluazifop-P, sethoxydim, and clethodim have been used with no damage to the sesame during this stage. To date, there are no ‘over the top’ herbicides to control broadleaf weeds. There is on-going research on directed sprays.
- This is the most vulnerable stage to perils: At the beginning of the stage, leaf eating insects can destroy the plants, but towards the end, the plants can usually grow out of leaf eating insects. With no weed control, most weeds will outgrow the sesame and cover it. High winds

with blowing sand can sandblast the plants or cover the seedlings. Rains with running water can cover the seedlings (Photo 17).



Photo 17. These seedlings were planted 8 days before and then had a 1" rain at 7 days with water running down the seed line. The mud on the cotyledons will slow down growth, but note the first true leaves emerging which are clear of mud.

### Juvenile stage

**Definition:** From third true leaves until the first floral buds are visible. The growing shoot can be pulled apart showing buds earlier, but this stage ends when the buds are visible without touching the plants.

**Time from planting:** From about 26 days to 37 days.

**Length of time:** 1.5 weeks.



Photo 18. This plant is at the 4<sup>th</sup> set of leaves with the 5<sup>th</sup> and 6<sup>th</sup> visible. Photo by A. Weisker.

**Description:** The juvenile stage is short and could have been combined with the seedling stage. At this point forward, several sets of leaves can be seen at the top (Photo 18), and the plants will start growing very fast. This is an important 1.5 weeks to the farmer because this is the time the plants are tall enough for directed spraying with herbicides. It is

also the first time that a farmer should consider moisture conditions for the first irrigation.

From the start of this stage, multiple leaf sets are visible, and the number of days between leaf sets equaling the previous set decreases. High moisture, fertility, and temperatures increase the plant height and the size of the leaves at this stage, but the length of the stage remains basically the same.

#### *Factors that shorten stage:*

- Drought. There have been many examples in flood or furrow irrigation where the irrigation water does not reach the end of the field. That dry end will start producing buds earlier than the irrigated part of the field.

#### *Factors that lengthen stage:*

- Rain or irrigation that cuts off oxygen to the roots. Sesame does better when there is no rain or irrigation until after this stage, as long as there is sufficient moisture in the soil.
- Cool night temperatures.
- Low soil fertility. As in the seedling stage, this is particularly evident in fields that have been planted after a disced in crop where there has been no additional fertilizer, and the plant material is tying up the nutrients.

#### *Juvenile farmer keys:*

- Farmers can be lulled to sleep during this stage because as shown in Fig. 3, in the first 34 days the plants reach about 1 foot in height and yet in the next 28 days, will quadruple in size to about 4 ft (Photo 19).



Photo 19. This sesame in no-till doubled its size in the next 10 days.

- At the start of this stage, farmers need to start preparing for cultivation and any fertilizer that is going to be added by side-dressing. By the end of this stage, there will be fields where the plants are taller than the front axle of the tractor.
- Towards the end of this stage, farmers should be watching the plants for indications that an



irrigation is necessary (Photo 20). If the lower leaves are wilting by around 2:00 PM, the plants should be irrigated within the next 3-5 days. Rains in the first 3 weeks after planting can fill up the upper soil moisture profile, and the roots may stay shallow instead of growing deeper. This can force the first irrigation earlier in the juvenile stage.



Photo 20. With no rains, this is the stage for the first irrigation. After this point, the crop should not be stressed by delaying irrigations.

- This is the last stage where it is advisable to stress the plants.

### Pre-reproductive stage

*Definition:* From first floral buds until 50% of the plants have open flowers.

*Time from planting:* From about 38 days to 44 days.

*Length of time:* About 1 week.

*Description:* The first floral buds appear in the leaf axils from the 4<sup>th</sup> to the 6<sup>th</sup> set of true leaves, depending on variety (Photo 21). Although it is possible earlier than 38 days to pull the leaves down and look closely at a bud forming, first floral buds are considered when the buds are visible without touching the plants. The buds start out greenish yellow and as they get closer to the day they will open, they will turn a more cream-yellow. On the evening before they open, they will turn a whiter color, pick up purple hue, and will double in size from then until the next morning when they open.

*Factors that shorten or lengthen stage:*

- There are no known factors that will shorten or lengthen the stage.

*Factors that accelerate the onset of the stage:*

- Dry portions of the field will bud first.
- High degree days will accelerate the start of first buds.

- By this stage, within a field there can be considerable variation in the number of days until floral buds. Dominant plants will bud first.

*Factors that delay the onset of the stage:*

- High moisture and fertility.
- Hail can damage plants and set them back, delaying the start of buds.
- Cool night temperatures.



Photo 21. First floral buds. The lowest flowers will open in the next few days and then begin to make capsules.

*Pre-reproductive farmer keys:*

- This is the most important farming stage to optimize production. The second application of fertilizer should be applied. If applying fertility with the water, there should be a split application with half during this stage and the other half at the next irrigation. If applying the fertilizer with a tractor, this will be the last opportunity to apply the fertilizer.
- This is the last time a tractor can enter the field to cultivate.
- From this stage until the late bloom stage, it is important to not stress the crop. Although the plants stress when they do not get adequate moisture, sesame is well adapted to going into a drought. It will drop the lower leaves in order to equalize the amount of transpiration with the amount of available moisture. If the crop is stressed to this point, irrigations will not bring

back the leaves, and depending how long the plants have been stressed, an irrigation may be counter-productive. It will set the plants back, will cause shedding of flowers, and can kill the plants.

- Although adding the first fertility after this stage has not killed plants, the crop does not look as healthy, and the plants transition from not having adequate fertility to having more than they expect.
- Many farmers have expressed a concern that the plants set their first capsules very high. Most of these farmers have grown soybeans, black-eyed peas, and/or guar. There are lines that have capsules in lower nodes, but to date, these have not had as much yield. In addition, with wider combine headers and terracing, it is difficult to get lower capsules into the combine.

## REPRODUCTIVE PHASE

The reproductive phase is divided into three stages: early bloom (Photo 22), mid bloom, and late bloom.



Photo 22. Field about to erupt in bloom transitioning between early and mid bloom. Photo by D. Peeper.

### Early bloom stage

*Definition:* From 50% flowering until capsules have formed in 5 node pairs.

*Time from planting:* From about 45 days to 52 days.

*Length of time:* About 1 week.

*Description:* Sesame flowers have five petals with the lower petal being longer and forming what is known as the lip. The lip is folded over the top of the flower, keeping it closed to around dawn when it opens and forms a landing strip for bees. Sesame is self-pollinating with the male and female parts in the same flower. Pollination normally takes place around the time the flowers open. Flowers open later in cool and/or overcast days. In the afternoon,

the corolla tubes drop off the flower, but the ovary that will form the capsule stays on the plant. There are varietal differences when the corolla will drop, and there are some lines where it does not drop and stays attached as the capsule forms. Within 2-3 days, the capsule will be visible (Photo 23) and will lengthen to about 1" within a week. There are varietal differences in the rate of elongation. The seeds form inside the capsules.



Photo 23. The plants are just beginning to set capsules. In the middle plant, the bottom capsule is just forming from an open flower 2 days before; the node pair above has lost its corollas from flowers the day before; the flower above opened the day of the photo and one corolla has already fallen; the node pair above the larger buds will open in the morning; and the node pair above the smaller buds will open in two days. Photo by A. Calderoni.

### Factors that shorten or lengthen stage:

- There are no known factors that significantly shorten or lengthen the stage.

### Early bloom farmer keys:

- It is normal in the beginning of flowering that every flower may not set a capsule. The first node is particularly known for not setting capsules. On S26, about 90% of the flowers will make capsules. In crops under no stress, there are fewer gaps. Often, a gap in capsule formation will indicate a stress such as heavy rains that cut down the oxygen to the roots, winds that blow flowers off the stem, or a cold spell that prevents fertilization of the ovule.
- In a drought, the flowers have a weaker attachment to the stem and can blow off even in



a mild wind. The distribution of missing capsules is not evenly spread, with most of the missing capsules at the lower main stem and the branches. In a 1997, Sesaco study on 5 lines similar to S26, the percentage of missing capsules was as follows: 16% on the lower main stem, 3% on the middle main stem, 0% on the upper main stem, 14% on the lower branches, and 16% on the upper branches.

- Many farmers have been worried about flower drop when the corollas shed at the end of the day. Normally, only the white/purplish part of the flower will drop – not the portion that will form the capsule (Photo 24).



Photo 24. One of the major concerns of new sesame farmers is that the flowers are shedding. In sesame, the corolla falls off in the afternoon, but the part of the flower that makes the seed, stays on the plant.

- The added fertility and first irrigation should have been in the pre-productive stage. If adding a split application of fertilizer through the water, this should be the stage for the last application. The concept is to have all the fertility in before the mid bloom stage, which is the most productive stage.
- There are no cookbook instructions for when to apply the second irrigation. Even within the same geographical area, the soils vary, the ET rates can change abruptly, the populations are different, the amount of soil moisture prior to planting is different, etc. Areas such as Arizona irrigate every

7-10 days, and areas such as Uvalde irrigate every 10-14 days. Where water is scarcer, the days between irrigations are longer.

- The plants are the best indicator for how much moisture is needed. In the summer, it is not unusual for the lower leaves of the plants to wilt in the late afternoon. By the next morning, the leaves have turgor. Each successive day, given the same sunshine and temperature, the leaves will wilt earlier. As in all previous stages, if the lower leaves are wilting by around 2:00 PM, the plants should be irrigated within the next 3-5 days.
- The best way to not stress the sesame is to keep a fairly regular irrigation schedule. If the length of time between the first and second irrigation was 10 days, the third and potentially fourth should also be ten days apart. There should be minor adjustments based on rain and ET rate. Irrigations can be delayed with rains, but in order to skip an irrigation, the rain should be comparable to the amount of water from the irrigation. One common problem is to have a rain with a few tenths and then delay the irrigation. By the mid bloom stage, the plants are pulling moisture from 2-4 feet deep and a light rain will not replenish deep moisture. If the ET rates climb quickly, then the irrigation should be put on sooner.

### Mid bloom stage

*Definition:* From 5 node pairs of capsules until the branches and minor plants (plants of lower stature, growing in part under the canopy of the taller plants) stop flowering.

*Time from planting:* From about 53 to 81 days.

*Length of time:* About 4 weeks.

*Description:* The beginning of this stage normally coincides with the branches starting to flower. However, the 5 node indicator is used because the start of flowering on the branches depends on population. In order for a branch to grow and become productive, sunlight must shine on the branch. In very dense populations, the plants at the center of the canopy and the minor plants may not have any branches. In thin populations, the branches will start putting on flowers and capsules before the 5 pairs of nodes indicator. In lines with no branches and triple capsules, the expression of triple capsules is usually stronger after the 4<sup>th</sup> node pair. The 5<sup>th</sup> node is not as significant in lines with no branches and single capsules.

This stage is the most productive stage because both the main stem and branches are

putting on flowers/capsules. In a study in Thailand (P. Suddhiyam et al. 2001 and pers. commun 2005) and in Korea (C.W. Kang et al. 1985), the number of flowers every day were counted on lines with branches and a single capsule. The results in Fig. 11 and Photo 25 show that in both studies, 70-75% of the flowers occur in the second and third week of flowering.

#### *Factors that shorten and lengthen stage:*

- This stage is almost totally dependent on the availability of moisture and fertility - the greater the amount, the longer the flowering period.

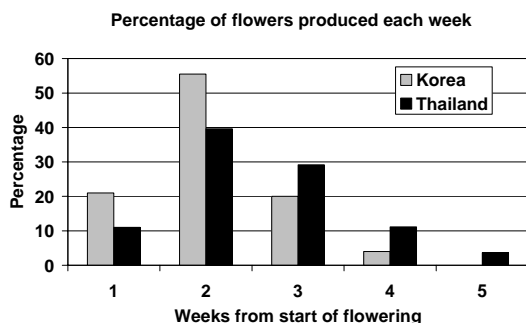


Fig. 11. Percentage of flowers produced each week in a Thai and Korean study. Even though the reproductive stage can go on for 6 weeks, weeks 2 and 3 produce 70-75% of the flowers. It is the most important two weeks of the cycle and the plants should not be stressed.



Photo 25. At the mid bloom stage, there are many flowers each day. This is the most beautiful stage.

#### *Mid bloom farmer keys:*

- The work done in Thailand and Korea points to the importance of having good fertility and moisture available prior to the mid bloom stage so that the plants have the resources to make the optimum amount of production.
- As stated before, this is the worst time to stress the crop by untimely irrigations. Delaying too long will force the crop to try to adjust to a perceived drought, but irrigating back too soon is almost as

bad. There are two types of sesame in the world: those bred for dry areas and those bred for rainy areas. Sesaco varieties are bred for dry areas. The sesame prefers not to have too much water at any time, and standing water even for a short time can kill sesame. Over-irrigation can reduce yields more than under-irrigation.

- If there is an unavoidable delay in irrigation, it may be better to stop irrigating. When the plants are stressed for moisture, the lower leaves will wilt more each day and the top of the plant may also droop. As mentioned before, within 5-7 days of severe wilting, the plant will drop its lower leaves, thereby reducing the transpiration rates. Depending on multiple factors, the plants will drop enough leaves that the moisture in the soil can support the plant, and the plants will wilt less each day. The plants may also stop flowering and will accelerate the filling of the seeds. If the plants in this state are irrigated, there is more stress than before in that the leaves cannot transpire enough moisture out of the soil to get oxygen to the roots, and the plants can die.
- S30 and S32 have an interesting character. When there is less moisture, the leaves do not wilt – they curl up and shift to avoid sunlight. In a crop planted north/south, in the morning in the plants portions in the sun, the leaves on the east side will curl. In the afternoon, the east leaves will return to normal, and the leaves in the sun on the west side will curl. As the sun sets, all the leaves will be at the normal flat state.
- One sign that the plants are running out of moisture is the number of flowers that are open in a day. In single capsule lines in mid bloom, each flowering head (the main stem and each branch) will have 2 flowers open per day. There are instances where the main stem may have 3 flowers open. However, in the latter case, the same main stem will usually only have a single flower open the following day. It is not unusual to have branches with less than 2 flowers when there are high populations. However, when a large percentage of the main stems are down to a single flower per day, the plant is running out of moisture and/or fertility. After a rain or irrigation, the number of flowers per flowering head will increase, but it will not be overnight. It takes time for the plants to switch gears and accelerate.
- One consistent problem in determining the need for irrigation is that when the plants are in full bloom, the roots are generally as deep as the



plants are tall. Most of the moisture is being drawn out of the 3<sup>rd</sup> or 4<sup>th</sup> foot of the soil. In Yuma in 1983, the Soil Conservation Service placed neutron probes in the sesame crop and found the deep moisture depleted, while the surface of the soil was almost muddy. The farmer needs to look at what the plants are indicating rather than kicking dirt and determining that there is moisture at the surface.

- In a high population from this stage forward, the plants may drop the leaves underneath the canopy that are not receiving light (Photo 26). This is not considered stress. Those leaves are transpiring moisture and without light, not performing optimum photosynthesis. If leaves in daylight are dropping, it is an indication of insufficient moisture and/or fertility.



Photo 26. Once the canopy closes and the light does not reach the lower leaves, they will begin to drop. This is normal. In wider row spacing with light reaching the lower leaves, the leaves will stay on longer.

- At the end of the cycle, it is possible to know the moisture history of the plants by looking at the internode lengths. The lengths get progressively shorter from bottom to top of the plant, but they reduce at a discernable rate. If there is an abrupt shortening of the internodes, the plants went into moisture stress at that time. When the plants do get the water, the lengths can remain about the same for several nodes or can actually increase.

#### **Late bloom stage**

*Definition:* From branches/minor plants not flowering until 90% of the plants have no open flowers.

*Time from planting:* About 82 to 90 days.

*Length of time:* A little over 1 week.

*Description:* On branched lines, the beginning of this stage is when the branches stop flowering. In unicum lines, the minor plants will stop flowering.

The onset of this stage generally coincides with the plants running out of moisture and/or fertility. As in mid bloom, there will be progressively fewer and fewer open flowers per day (Photo 27).



Photo 27. In the late bloom stage, the flowers are at the tips of the plants and within days, there will not be any new flowers.

This is a very difficult stage to determine because at times, it is very abrupt and clear and under other conditions, it stretches out over a long time. With a given line in different years, one year it appears the stage has just commenced, and the next week it has ended. In another year, it appears that the stage has commenced, and the next week the field still has the same level of open flowers because of a rain. In Texas and Oklahoma, the rainfall is generally accompanied by lightning, and thus, the moisture will often bring down nitrogen from the atmosphere, slightly increasing fertility. With the newly available moisture and fertility, the plants keep flowering at a reduced rate for as much as two weeks.

The end of the stage is when 90% of the main stems do not have an open flower. It is very important that flower termination be determined in the mornings, before the corollas have fallen.



There are lines that drop their corollas as early as 1:00 PM and then appear to be no longer flowering.

In the mid bloom stage, leaves under the canopy will drop. In this stage, many plants will start having yellow leaves at the bottom, in the light, and they will begin dropping. This is the start of natural self-defoliation, to be discussed in the ripening phase below.

At the top of the plants, there is a higher percentage of flowers that do not become capsules than on the lower parts of the plants. The amount is both genetic and environmental. There are lines that never produce capsules at the top, and lines that may or may not produce them, depending on moisture and fertility. The level of temperatures that begin to affect growth in the final stages, as yet, has not been determined because no two years are alike. In some years, there are cold fronts that come through and when temperatures return to normal levels, there is little effect. In other years, the weather is generally cooler, and the night temperatures appear to be more important than the day temperatures.

The sesame plants will indicate cooler nights by the flowers showing more anthocyanins, they are deeper purple. The rule of thumb is that sesame is affected by night temperatures of 40-50°F. Genotypes react differently to cold: some will stop flowering; some will flower but will not set capsules and/or seeds; some will flower and set capsules and seeds.

*Factors that shorten stage:*

- Very hot period with low humidity.

*Factors that lengthen stage:*

- Cool weather with high humidity and rain.

*Late bloom farmer keys:*

- Most sesame fields at this stage are like doughnuts, in that the outsides of the fields are different than the majority of the field away from the roads and turn rows. The sesame in the middle of the field will generally stop flowering before the edge plants, and therefore, it is difficult to windshield this stage. The farmer must stop and walk into the field – preferably in known areas that mature earlier for other summer crops.
- This stage is important because it will determine the final irrigation. The most common question is how many irrigations sesame should have. There is no cookbook answer. Most irrigated farmers soon learn the appropriate number given their soils, ET rates, populations, fertility, and irrigation methods. In starting out, the farmer should continue applying irrigations until the late bloom

stage as long as the crop is not following vegetables that have left substantial fertility in the ground. Following vegetables, the farmer should stop irrigating about 5 weeks after flowering has started to induce the end of the crop and hope for no rains. In normal conditions, the plants will use up the fertility and will slow down flowering on their own. If on a fixed day schedule and the next irrigation is due at the beginning of late bloom, irrigate. If the next irrigation is due after at the end of late bloom, do not irrigate. If in doubt, do not irrigate.

- As with any crop, there will be areas of the field that have stopped flowering (Photo 28) while others are still in mid-bloom. In sandier soils, the plants will generally stop flowering sooner. In low areas, in some years there will be too much moisture which will damage the plants, and that will be the first area to stop flowering, while in other years, the same area may have the optimum amount of moisture and will be the last to stop flowering. Areas with high populations will stop flowering first.



Photo 28. At the end of the late bloom stage and beginning of the ripening phase, the plants have stopped flowering and the leaves are turning a lighter green. The bottom leaves have fallen off. As the seeds in the capsule in the leaf axil mature, the leaf below will drop off. Photo by G.C. Musa.

- Given the same conditions, fields planted on successive weeks will have the same sequence of reaching the late bloom stage. However, conditions are rarely equal. Some fields will have more fertility and moisture than others. In trying to understand the harvest sequence, the sequence the fields reach final bloom will normally be the same sequence for harvest.

## **RIPENING PHASE**

The ripening phase is not divided into stages. Technically, the ripening process begins in the reproductive phase.

*Definition:* From 90% flower termination until physiological maturity. Physiological maturity (PM) is the date at which 3/4 of the capsules on the main stem have seed with final color and a dark tip. In many lines, the seed will also have a dark seed line on one side.

*Time from planting:* About 91 to 106 days.

*Length of time:* A little over 2 weeks.

*Description:* The concept of PM in sesame was developed by M.L. Kinman in the 1950s (pers. commun.) in order to determine the earliest date that the plants could be cut and still harvest over 95% of the potential yield. When the seed has final color, the seed can germinate. If the plant is cut at PM, most of the seed above the 3/4 mark will continue maturing sufficient for germination but may be lighter. Since even in a fully mature plant, the seed weight produced at the top of the plant is low; this loss of seed weight does not seriously affect the potential seed yield of the plant. PM is important in northern US crops where there is a potential for an early frost or freeze. After PM, the majority of the potential yield can be harvested, even if the plants were terminated by cold.

In Uvalde, the rule of thumb is that PM will move up 6-7 node pairs per week below the 75% PM level, and 4-5 node pairs per week above the 75% level. In West Texas, at higher elevations with cooler nights, the weekly rate has not been determined, but in 2003, with limited data, it appeared that just below the 75% level, the progress was about 3-4 node pairs per week, and above it, 1-2 node pairs per week. From the Lower Rolling Plains through Central Oklahoma, the temperatures are similar, even though there are large differences in latitude. This area shows an intermediate behavior between Uvalde and West Texas. More data is necessary to quantify the rates in all locations, but from additional observations made in 2004 through 2006, there is no doubt that ripening is slower in cooler temperatures.

Technically, sesame is in the ripening phase from the mid-bloom stage through the early late drydown stage. Among sesame researchers, there is no universal definition of mature seed. Some define the seed as mature when it can germinate. Others define the seed as mature when it reaches its maximum dry weight. There has been little research to determine how much difference there is between varieties. The two previous methods can only be done through laboratory analysis, and for farming, it is better to have something that the farmer can see in the field. Sesaco defines the seed as mature when the placenta attachment between the seed and the capsule dries, and the seed coat gets its

final color (turns from milky white to a buff color) (Langham et al. 2008). Generally, the seeds get their color first at the lower capsules and maturity progresses up the stem.

During this phase, most of the leaves fall off the plants. Sesame starts self-defoliation in late bloom stage, and the leaves have mostly fallen off by in the initial drydown stage. Generally, leaves will turn yellowish green (some lines go to a pale yellow or a deep yellow) before dropping (Photo 29). In many lines, the lowest leaves turn yellowish when the canopy blocks the light, and they will drop even while the plants are in full bloom. As mentioned previously, the leaves may drop due to drought. Dropping of leaves because of shade or drought is not considered the maturity self-defoliation.



Photo 29. As the ripening phase proceeds, more leaves are dropped without using any chemical. It is important to not apply a harvest aid at this point as there will be a substantial yield reduction because most of the capsules at the top of the plant have not filled the seed. Rule of thumb (with many varietal exceptions) is that a capsule has its full weight when the leaf underneath drops off.

As the plant stops flowering and matures, the leaves will drop from the bottom of the plant to the top. There are a few US lines where the plants hang on to a few node pairs of lower leaves while dropping the leaves in the middle node pairs. However, in these lines, the lower leaves drop as the plants enter the drying phase. In some fields, the upper leaves can hang on longer providing some photosynthesis for seed fill in the upper capsules. These will also drop long before the combine (Photo 30). If the plant is killed prematurely by insects or disease, the leaves will dry on the plant and will generally only fall after rain and wind or may not drop off at all.

In the US, the leaf below the capsule will drop as the capsule matures, and the capsule and plant will turn a yellowish green. At PM, most

genotypes are yellowish green with some more green and others more yellow. In order to use the color as a cue to look for PM, the farmer needs to be familiar with the color of that variety. For example, S27 is more green than yellow; S29 is more pale yellow; S25/S32 are a deeper yellow; and S24/S26/S28 are a balanced yellow green. There are lines that have dark green capsules with mature seed and lines that are very light yellow with immature seeds.



Photo 30. The leaves have fallen off and the seed to the plants are very close to PM. Note that the plants have a bit of green left on the top.

#### *Factors that shorten phase:*

- Lower moisture and/or fertility.
- Higher temperatures.

#### *Factors that lengthen phase:*

- Higher moisture and/or fertility.
- Lower temperatures.

#### *Ripening farmer keys:*

- This is not a necessary stage for farmers combining directly. However, PM is important because after that point, the crop is less susceptible to yield loss due to frost or disease. It is also an indicator that the time to use harvest aids is approaching.
- The determination of physiological maturity is important if the crop is going to be swathed. In the 1950s, the plants were swathed at physiological maturity. Swathing is still done in Arizona because the ground is under constant cultivation, and farmers want to turn the ground to the next crop. Swathing was tried in Texas and Oklahoma, but there is a higher probability for rain and dust storms making swathing an undesirable option in that there is a high potential to reduce yield and quality.
- It is easy to determine the PM of a plant. Determination of PM for a whole field requires a

judgment because fields are rarely uniform. Edge areas with more fertility, low population areas, and wetter areas will all have later PM. The farmer must determine the proportion of these areas to the whole field to declare PM of the field.

- In the 2005 desiccation study, all harvest aids stopped production of seed even though the plants did not dry down on some of the harvest aids. All yields of harvest aids put on PM were lower than the yields of the harvest aids applied in the next stage.
- In a 1997 Sesaco study, cutting plants one week prior to PM reduced the yield as much as 15%.

## **DRYING PHASE**

The drying phase is divided into three stages: full maturity, initial drydown, and late drydown.

### **Full maturity stage**

*Definition:* From physiological maturity until 90% of all the plants have all seeds mature. Sesaco does not take data on days to all seeds mature, and thus, the following range is an estimate based on one year of data.

*Time from planting:* From about 107 to 112 days.

*Length of time:* About 1 week.

*Description:* With direct harvest without the use of harvest aids, this stage is not important. With swathing or harvest aids, the plants will be killed, and the seeds will no longer fill. At the end of this stage, the plants will have the highest potential yield and can be terminated to accelerate drydown. However, since the capsules in the top 2-3 node pairs contribute little seed, the practical time may be at some point between PM and all seeds mature. In essence, the purpose of swathing or applying harvest aids is to harvest sooner, and thus, the practical time may be better.

In a 1998 Sesaco study, plants were broken into 5 sections to understand the importance of each section in terms of contributions to yield. The number of node pairs on the main stem were counted and divided into thirds [lower main stem (LMS), middle main stem (MMS), and upper main stem (UMS)]. The branches were then pushed to the main stem, and where the lower main stem was to be cut, was designated as lower branches (LBR) and the rest was upper branches (UBR). There were no branches that reached the upper main stem. The study grouped the plants by phenotype and then averaged the results. Each section was analyzed in terms of hundred seed



weight, seed weight per capsule, and percentage of seed in each part of the plant. In looking at this data, S25 and S29 have few branches and are single capsule, while S26, S28, and S32 have many branches and a single capsule per leaf axil. Table 5 and Fig. 12 show the relationship between plant segments on hundred seed weight.

Branch	Caps	All	LMS	MMS	UMS	LBR	UBR
None	1	.298	.296	.305	.290		
Few	1	.286	.290	.295	.283	.271	.269
Many	1	.305	.322	.322	.306	.286	.284
None	3	.271	.276	.270	.264		
Few	3	.245	.241	.246	.246	.237	.252

Table 5. Hundred seed weight (grams) in different plant segments by phenotype. The average number of seeds in a capsule is 70.9, with more seeds in the central capsule of a triple capsule line than in the axillary capsules (All = average of whole plant, LMS = lower main stem, MMS=middle main stem, UMS=upper middle stem, LBR=lower branches, UBR=upper branches.)

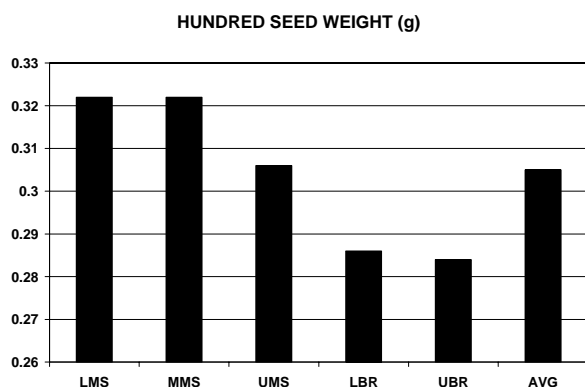


Fig. 12. The relative hundred seed weight in a many branched single capsule line such as Sesaco 26.

There can be as much as 12% difference between the smallest and largest seed on the plants. In most phenotypes, the heaviest seed is in the middle of the main stems, with the smallest seed out on the branches. In general, single capsule lines have larger seed than triple capsule lines. In addition, the seed in the tips of the capsules is smaller than the seed in the middle of the capsules.

Branch	Caps	All	LMS	MMS	UMS	LBR	UBR
None	1	.206	.196	.220	.203		
Few	1	.195	.194	.215	.203	.148	.158
Many	1	.204	.215	.242	.225	.168	.187
None	3	.156	.157	.163	.140		
Few	3	.131	.140	.141	.122	.114	.116

Table 6. Seed weight per capsule (grams) in different plant segments by phenotype. (All = average of whole plant, LMS = lower main stem, MMS=middle main stem, UMS=upper middle stem, LBR=lower branches, UBR=upper branches.)

Table 6 and Fig. 13 show the relationship between plant segments on seed weight per capsule.

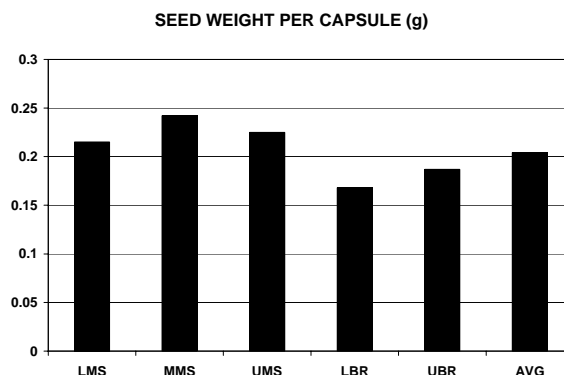


Fig. 13. The relative seed weight per capsule in a many branched single capsule line such as Sesaco 26.

There is a much larger variation between the sections with as much as a 31% difference between the heaviest and lightest capsules. As with hundred seed weight, in most phenotypes the heaviest capsules are in the middle segment of the main stem and the lightest on the branches.

In experimental fields where there is thinning, the seed weight per capsule would be expected to be fairly uniform, but in unthinned fields, there is a lot of variation between dominant plants and minor plants. In a 2004 Sesaco study, two capsules were harvested from the middle of the capsule zone on 50 consecutive plants of Sesaco 26 in a row. As can be seen in Fig. 14, there is considerable variation between dominant and minor plants.

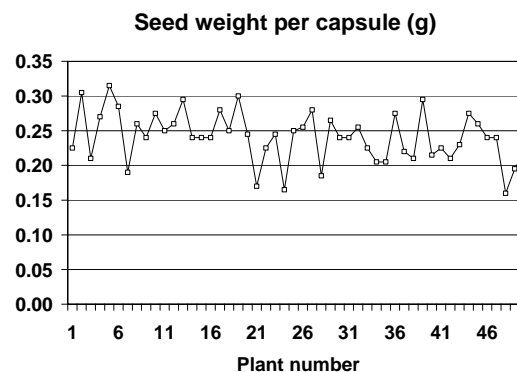


Fig. 14. Seed weight per middle main stem capsule from 50 consecutive plants. There is a large variation between dominant and minor plants, with the dominant plants having the highest weights.

Table 7 and Fig. 15 show the relationship between plant segments on percentage production. In the upper portion of the main stem, there is lower percentage of seed than would be

implied from the seed weight per capsule in Table 6 because there are fewer capsules in the upper portion of the plant. Although there is a significant lower seed weight per capsule on the branches, there are more capsules on the branches, resulting in a significant amount of seed in the branches and even more in lower populations.

Branch	Caps	LMS	MMS	UMS	MS	LBR	UBR	BR
None	1	31.2	37.1	31.7	100.0			
Few	1	27.1	28.8	23.7	79.6	9.9	10.5	20.4
Many	1	22.4	23.5	17.7	63.6	15.9	20.5	36.4
None	3	25.5	41.8	32.7	100.0			
Few	3	19.1	32.5	26.9	78.5	10.6	10.9	21.5

Table 7. Percentage of seed in different sections of plants. (LMS = lower main stem, MMS=middle main stem, UMS=upper middle stem, MS = total in main stem, LBR=lower branches, UBR=upper branches, BR = total in branches).

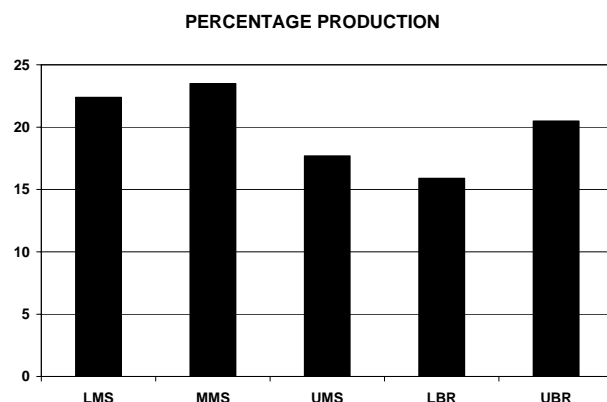


Fig. 15. The relative percentage of seed in a many branched single capsule line such as Sesaco 26. This study was done on 30" beds in a normal population and the branches contributed 36.4% of the yield. In wider row spacing and in lower populations, this percentage can be as high as 60%.

In the main stem versus the branches, the ratio of seed changes considerably with population, with less seed in the branches in high populations and more seed in the branches in low populations.

#### *Factors that shorten phase:*

- At this point, it is not known if lower moisture and/or fertility shortens the phase. There is not enough data.
- High temperatures.

#### *Factors that lengthen phase:*

- Low temperatures – see description of ripening phase.

#### *Full maturity farmer keys:*

- This stage is important if a harvest aid is being used or if the crop is being swathed but is not important for direct harvest.

- Determination of the status of the whole field requires judgment because the fields vary in fertility, population, and moisture, and the areas reach the end of this stage at different times.

The following applies when using a harvest aid for this stage and the initial drydown stage. A harvest aid may be used in this stage since the majority of the seed weight is already on the plant. There are other considerations:

- Generally, the sooner the application, the better the drying weather and the sooner the crop is cleared from the field for the next crop.
- With harvest aids such as glyphosate, most plants absorb the desiccant better when there is still some active growth, and thus, the harvest aid is more effective. With harvest aids such as diquat, the plants dry down faster later in the stage.
- Another advantage of a harvest aid is that it will also kill the weeds. This is particularly good for grasses and johnsongrass since they will often drop their seeds before combining. Grass seeds can significantly reduce seed quality and lead to price discounts.
- Another advantage of a harvest aid is that it will even up a field that is not uniform due to soils, late germination, or differences in fertility and/or moisture.

The following applies when there is regrowth for this stage and the initial drydown stage:

- If the crop starts regrowth and the crop is not going to direct harvest, a harvest aid should be applied as soon as possible. It will take time for the plants to form mature seed in the regrowth capsules. In the meantime, the lower capsules on the main stem will dry and can lose seed. The seed in the regrowth has lower seed weight and will reduce test weight. When stopping the crop as soon as possible, the regrowth seed will go out of the back of the combine. With later application of harvest aids, the seed in the regrowth will be immature and can affect seed quality.
- When using a harvest aid, the regrowth leaves will generally not drop from the plant as they dry down, and the leaves can be a problem in separating the sesame from the trash.

#### **Initial drydown stage**

*Definition:* From all seeds mature (Photo 30) until 10% of the plants have one dry capsule. The plants used should be green plants that have natural drydown, excluding plants that have died from a disease. In windy areas, the plants may

rub against each other and break down capsules. These will become dry, but these are not considered as dry capsules.

*Time from planting:* from 113 to 126 days.

*Length of time:* About 2 weeks.



Photo 30. The plants turn a lighter green with a yellow tinge and begin to dry down. The leaves have normally dropped by this point.

*Description:* Earlier, lines were described that have dry capsules at the bottom of the plant while the plant is still flowering. Since the 1940s, lines have been selected that do not have open capsules until the plants are past PM (D.G. Langham and Rodriguez 1945). The time between PM and first dry capsule is known as the harvest window, and US varieties have been developed with as much as 21 days of harvest window. A wide window is important when the crop is swathed to decrease the amount of seed lost from the dry capsules. However, if the crop is going to direct harvest, a long harvest window is a disadvantage in that it will delay harvest.

The main stem will generally have dry capsules before the branches (Photo 31), but the branches will generally dry down before the main stem. The lower capsules dry first, with the top capsules drying last. Parts of the stems will dry before all of the capsules are dry. The pattern of stem drydown differs in that in some cases, the middle of the stem dries first and then goes in both directions; in others, the top stem dries first and goes down; in others, the bottom stem just below the capsules dries first and goes up and down. In any sequence, the lowest part of the plant between the lowest capsules and the root is the last to dry.

The only exception to the lowest part drying last is when the plant succumbs to root rot, then the drying will be from the very bottom of the plant up, and the drydown will be much faster. There are three root rots (*Fusarium*, *Phytophthora*, and *Macrophomina*) that affect US sesame. The newest varieties have much greater tolerance than varieties

developed in the mid 1990s, but there are still plants that die earlier than the rest. Plants are more susceptible to the root rots when there is stress; for example, low soil moisture at the seedling stage when the root is racing to keep up with the moisture; the use of some root pruning herbicides which will not kill the plant but will offer a point of entry for the root rot; moisture stress in both directions – too little or standing water. Plants that die should not be counted in the 10% of plants with dry capsules.



Photo 31. The capsules dry down first followed by the stem

*Factors that shorten the phase:*

- Lower fertility and moisture, higher degree days, lower humidity, sunshine, constant winds, frost, and freeze.

*Factors that lengthen the phase:*

- The inverse of above - higher fertility and moisture, lower degree days, high humidity, cloudy days, fogs, and dews.

*Initial drydown farmer keys:*

- If using harvest aids, this stage is the optimum time. The seed is mature and filled to the top of the plant, but harvest aids can be used in the next stage.
- The first dry capsules are the cue for the farmer to get the combine ready.
- Do not panic over the capsules opening – they are supposed to. There will be some seed lost out of the tips of the capsules, but there is more seed in the bin than there ever has been before. With improved non-dehiscent capsules, there is even less shatter loss.



## Late drydown stage

*Definition:* From first capsule drydown until enough drydown for a combine to produce 6% or less moisture seed.

*Time from planting:* From 127-146 days.

*Length of time:* About 3 weeks.

*Description:* Of all of the phases, the final drydown phase is the most variable in terms of length of time in the phase. In some years, it seems like an eternity to move from 50% drydown (Photo 32) to 95% drydown (Photo 33). In other years, it can happen quickly.



Photo 32. As the plants dry down, there is a brown hue to the field. Normally, the plants near the edge of the field stay greener and thus, if the farmer does not get a high look, he may not realize that the field is as brown as it can be.

If the reproductive phase is shorter because of lack of fertility, this phase will have a shorter time from planting but will not necessarily change in terms of length of time in the phase. However, if the reproductive phase is shorter because of lack of moisture, this phase will have shorter time from planting and length of time in the phase. On the other hand, the fall has more rain than the summer in Texas and Oklahoma, and the reproductive phase can be shortened; but sufficient, late rains will keep the length within the drydown phase the same.

When the capsules are dry, they open at the tip, allowing the seed to fall out. For 7,500 years, sesame has been harvested manually. The farmers cut the plants when green and shock the plants to dry. The sesame is then inverted and struck to shake out the seed. There are some super shattering capsules (Photo 34), but most sesame in the world is shattering (Photo 35). Farmers have thrown out any mutations that keep the seed from just falling out when the capsules are inverted.



Photo 33. Plants to the left are not quite dry, as you can see some yellowish hue in the field still and one yellow plant in the right center. Although the capsules and the seed are dry, the moisture in the green stems will be introduced into the bin sample and raise the moisture. If there are only a few plants that are green, the combine should enter the field in a representative area to test the moisture but should not cut a whole bin until determining the moisture is 6% or below.

Two closed capsule mutants have been found: the indehiscent character (Photo 35) was discovered by D.G. Langham in 1943 (D.G. Langham 1946) and the seamless character (Photo 36) was discovered by D.R. Langham and D.G. Langham in 1986 (D.R. Langham 2001). Although initially these were thought to be the solution for mechanization, the combines damaged the seed too much. The indehiscent gene was distributed throughout the world with hundreds of breeders trying to reduce the damage. In the 1950s, there was hope in combining the indehiscent allele with a character known as "papershell" capsules (Culp 1960). However, when the indehiscent and papershell characters were joined in Sesaco 01, it was still not enough. In combining closed capsules, the concaves must be closed and the cylinder speed increased. Many operators have added rasp bars or spikes to increase the threshing surface. Essentially, each capsule must have opposing forces on each side and some seed in each capsule is damaged.

In addition, the cutting action often crimps the opening created on the capsule and the seed cannot flow out. Sesame seeds have a thin seed coat, contain over 50% oil, and can be damaged easily. Even if the seeds are not broken, they can be bruised, which will create free fatty acids that will turn the seed rancid.



Photo 34. Super shattering capsule. In some areas of India, there are capsules that open all the way. These types are cut and moved to a threshing floor while green. The shocks are moved every couple of days and the seed collected.



Photo 35. Shattering capsule. In most of the world, the plants are cut when they are green and left to stand in the field in shocks until they dry down. The bundles are then inverted and the seed falls out.



Photo 36. Indehiscent capsule. This capsule will not open when left to dry in the field, but the seed will not release in the combine without excessive force which damages the seed.



Photo 37. Seamless capsule. This capsule will not open at drydown or release its seed in the combine without damaging the seed.



Photo 38. Non-dehiscent capsule. This capsule will hold its seed while the plants dry down in the field and will release them in the combine. The capsule at the rear has been cut in half and the membranes have been razored to show how the seed is positioned in the capsules. Photo by Jay Simon.



Photo 39. Improved non-dehiscent capsule. These capsules hold their seed better and will still release it in the combine. This photo was taken on Dec 17 when the crop could have been combined the first week of Oct. The seed is still in the capsules 76 days after the plants were dry for combining.

Sesaco bred non-dehiscent (Photo 38) sesame (D.R. Langham 2000, D.R. Langham 2001, D.R. Langham and T. Wiemers 2002, D.R. Langham 2004a, D.R. Langham 2004b, D.R. Langham 2006, D.R. Langham 2008a) by joining 6 characters so that the seed is held in the capsules until in the combine, and then most of the seed is threshed out of the capsules in the feeder housing of the combine.

The concaves can be opened and the cylinder speed slowed down. The key was the development of a stronger placenta attachment by accumulating genes to improve the original placenta attachment discovered by D.G. Langham (Langham et al. 1956). In addition, there were genes with minimal opening and genes that held the two halves of the capsule together until the combine. There is an adhesion that is similar to the office sticky note that holds the halves together but not too much. There are lines that have better shatter resistance than the present varieties, but they hold the seed in the capsules in the combines. Capsules with tips that are more closed also are susceptible to forming mold in the capsules. Non-dehiscent sesame is a balance between the capsules holding the seed until the combine cuts the plants but then releasing the seed inside the combine with minimal force.

Recently, Sesaco has developed improved non-dehiscent (Photo 39) sesame (D.R. Langham 2008b, D.R. Langham 2008c, and D.R. Langham 2008d). This sesame has additional seed retention that holds more seed until the combine, and yet still releases the seed in the combine with minimal damage. These new varieties will show seed in the tips of the capsules four weeks after the field could have been combined, allowing for more flexibility at harvest.

Many researchers continue to try to close up the capsule at drydown. However, there is tremendous advantage in opening the capsule in terms of accelerating harvest. The seed at maturity has about 60% moisture and for combining, it has to reach 6%. With a closed capsule, all of this moisture must travel from the seed through the capsule wall; whereas with open capsules, the moisture can escape out the top. In Yuma, in 1982 two lines were swathed the same day – one with a closed capsule (indehiscent) and the other with an open capsule. There were rains on both windrows, which delayed harvest. When the open capsule windrow was combined, the closed capsule windrow had too much moisture in the seed. Additional rains kept the combines out of the indehiscent field for 6 weeks. At that point, there were weeds growing through the windrow further complicating harvest. When

combining direct in subsequent years, if the combines were operating in the field before a rain, the combines could re-enter the open capsule lines 3-5 days earlier than the closed capsule lines. The capsule walls absorb moisture and it is easier to dry out from both sides of the capsule wall than just from the outside.

In US sesame with combine harvest, the consistency of the stem has many effects on the phenology. In many US field crops, the harvesting equipment does not take the stem into the machine (corn and cotton) or only takes the top part of the plant (wheat, sunflowers, safflower, and sorghum). In these crops, strong stems can be bred to prevent lodging. In crops such as sesame, soybeans, other types of beans, and guar, the majority of the plant enters the combine. In order to breed for lodging resistance in sesame, there has to be a balance between creating a stem that will reduce lodging and can be cut without damaging the cutter bars, be pliable enough to move through augers, and break up in the combine. Woodier stems take longer in the vegetative and early reproductive stages because the plants are using resources to produce more lignins. These woodier stems hold their moisture longer and take longer to dry down in the drydown stage.

#### *Factors that shorten the phase:*

- Lower fertility and moisture, higher degree days, lower humidity, sunshine, constant winds, frost, and freeze.

#### *Factors that lengthen the phase:*

- Higher fertility and moisture, lower degree days, high humidity, cloudy days, fogs, dews, and later planting.

#### *Late drydown farmer keys:*

- Again, the capsules are supposed to open. Closed capsules are the enemy of yield and seed quality.
- By this stage, the combines should be ready. A farmer needs to be looking at his fields every 3-4 days because something like a system that brings in very low humidity, can change the crop very fast. Through plant breeding, the shatter resistance and lodging resistance of sesame have been increased. There is less seed loss than there has ever been. However, once the crop is dry, nothing good can happen. The crop should be combined as quickly as possible (Photos 40 and 41).
- In contiguous fields around pivots, there is both irrigated and dryland sesame side by side. In a



dry year with no rain late, the dryland will dry down earlier than the irrigated. With some rain late, the dryland will dry down after the irrigated.



Photo 40. Any color combine will work in sesame with gentle settings to avoid damaging the seed which has 50% oil. Photo by J. Riney.



Photo 41. The current varieties have been developed with lower plant height to allow a platform header to be used. Photo by J. Riney.

- The important question is how soon can the combine enter the field? Generally, the earlier the combining, the higher the yield. However, combining too early can lead to quality discounts from high moisture, greater dockage and foreign matter, and more broken seed. Seed moisture should be at or below 6% at harvest. While this is low compared to other crops, with 50% oil content, 6% sesame is equivalent to 12% corn. There have been many attempts to find a way of drying down the seed after harvest, as is done in other grains. All have failed. Wet sesame will go rancid and is worthless, even as feed. Do not harvest under high moisture. There are serious price discounts, and the load may even be rejected.
- Like most crops, the best way to determine if the crop is ready to cut is to put the combine into a

representative part of the field and test the moisture. Choosing a representative part is critical. Some operators enter the driest part of the field, get a green light on moisture, and are "shocked" when the moisture of the whole truck is too high because they moved into greener sesame. The common complaint is, "But I checked the moisture."

- As shown in Fig. 16, for Sesaco 26 the number of days in the drying phase can vary considerably. Although a nominal time without harvest aids is 35-45 days, in a drought, the drying will be much faster, and with rain late, the drying can be delayed.

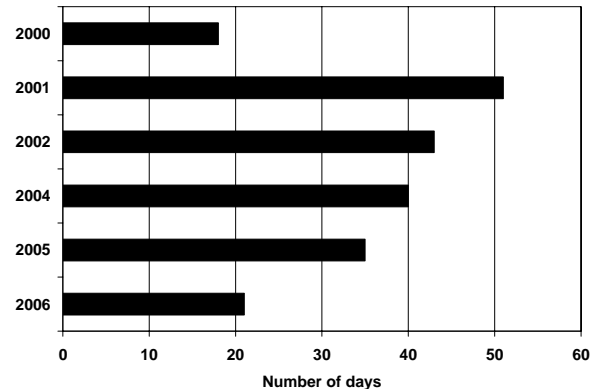


Fig 16. This shows the amount of variation in the drying phase for Sesaco 26 planted in the same location, within a couple of weeks, in six different years. Do not look at a calendar to know when to harvest – look at the fields.

- There are visual cues for dry sesame: there will be dust coming out of the feeder housing; the angle of repose (angle of the stack in the combine bin) increases with higher moisture; when turning at the end of the row, dry sesame will shift and somewhat even out and wet sesame will not; experience combiners can smell the moisture in the seed in high moisture sesame. However, these cues differentiate between 5 and 8% sesame, but there is a continuum making all of these cues difficult to use. Experienced combiners can tell when it is very dry or very wet but may not be able to differentiate 5.5 versus 6.5% sesame.
- At the end of the day, the sesame may be below 6%, but the seed will rehydrate during the night. With dew, the capsule can actually close up. It will take time in the morning for the sesame to dry out again. In 1995, a combine in Uvalde stopped combining at about 5:00 PM with the seed under 6% moisture. The next morning, the combine reentered the field about 10:00 AM when the dew had burned off, and the moisture

was over 10%. By about 2:00 PM, the combine restarted with moisture under 6%.

- Generally, in South Texas the prevailing winds are from the Gulf of Mexico and bring in moisture, while in West Texas/Oklahoma, the winds are from the dry west out of the deserts or north out of the mountains. With the high humidity in South Texas, there is a limited amount of time for combining in order to cut to the appropriate moisture. Normally, combining will start after noon and ends near sunset when the dew is starting to show. With lower humidity and more wind in West Texas or Oklahoma, there are times that combines have cut through the night.
- The combines can cut to the appropriate moisture with some green plants but should not cut through areas where all the plants are still green. There can be more green in low humidity days, strong sunshine, and wind.
- One of the problems with a freeze is a false indication of the extent of the drydown. With natural drydown, as the stems dry down, they will turn brown and lose most of the moisture. After a freeze, the plants will turn brown within days but will still have too much moisture to combine. Green plants will take 7-10 days to dry down after a hard freeze.

## EFFECTS OF THE ENVIRONMENT

### Light

As explained before, light is essential in branch and capsule development. In Uvalde 'time of planting' studies, there is a high positive correlation between yield and total light units in the vegetative and reproductive phases. In planting the same varieties at the same latitude in Oklahoma and Korea, the plants are taller in Korea under similar moisture and fertility inputs (pers. obser.). One possible explanation is that in Korea, there is less sunshine in the Suweon area due to smog and cloudy days. In planting the seed 30 miles apart in Uvalde, under similar moisture and fertility inputs, the plants to the south are usually shorter. One possible explanation is that in the north, the fields are near the hills, and the sun usually breaks out of the overcast 2-3 hours later in the morning. It appears that weak light promotes stem elongation and strong sunshine reduces it; however, it does not appear to change the number of days in the stages.

In 2007, there were 42 consecutive days where there was rain within 50 miles of San Antonio, TX, and there was very little sunshine. The lack of sunlight delayed the growth, and the whole nursery with over 2,000 different lines was from light yellow

to very yellow. Within 3 days of sunshine, most of the field had greened up.

### Rain

As stated in most of the phases and stages, the amount of moisture has an effect on the length of time in each stage. The ideal rain pattern is enough rain prior to planting the crop to fill the soil profile; a planting rain that will provide enough moisture to plant and to join top and bottom moisture; 30 days of dry weather (in a dry area so the root goes deep – not as important in a wet area); rains about every week for the next 50 days, and then no rain until the crop is harvested. The rains should be light enough so that the moisture percolates into the soil into the root zone. Continual rains saturate the soil and keep oxygen out, yellowing the plants, and delaying the vegetative phase. The actual rain has the following effects on the stages:

- In the germination stage, a rain will often move the seed deeper in the soil, delaying emergence. In certain types of soils, a rain can create a crust, delaying or preventing emergence. A rain will also cool down the soil, and if planting at close to the minimum required temperature, the coolness can prevent germination.
- At the seedling stage, rain can splatter mud up on to the cotyledons and first few leaves, reducing the photosynthetic surface and delaying growth. In some cases, a rain can cause erosion and cover seedlings with mud. Once the cotyledons have inverted and opened, the seedling has little push. If the seedlings are totally covered, they will die. If part of the seedling is exposed, it can recover, but the stage will be delayed.
- In the ripening phase, if there has been a drought, a rain can lead to regrowth which was discussed in that phase.
- In the drying phase, rain can reduce shatter resistance, but with the new improved non-dehiscent varieties, there is significant less shattering and loss of seed.
- In 2000 in Oklahoma, there was continual rain, drizzle, fog, and overcast conditions that lasted over 3 weeks. With high temperatures, a mold formed over all of the crops, gardens, and forests that ruined the sesame, soybeans, sorghum, and cotton. None of the crops could be harvested.
- Rain can germinate seeds that were in dry soil at planting. The greater the difference between the initial germination and this late germination,

the greater the farming problems due to differing maturity dates.

- Sesame plants suffer from standing water and will usually die if the water is on the stem for even a short period of time. Excessive rain that leads to water logging in low spots can kill sesame in any phase.
- In trying to predict production in an area, it is more important to know the timing of the rains in relation to the stages than to know the total amount of rain.

### **Drought**

As stated earlier, sesame is drought tolerant, but as with every crop, will do better with more moisture. In US crops there is a weather phenomenon in the summer known as a “Texas high,” when a high pressure area sets up over Texas and southern Oklahoma. During this time, it will not rain for about 6 weeks with the drought starting sometime in June – coincident with the vegetative and reproductive phases. Even without this Texas high, there is little rain during the summer (usually lower than 5”) during the growing phases. Sesame persists in these conditions, and in extreme conditions, pigweed has died while the sesame plants have survived. The indeterminate nature of sesame allows it to bridge these drought periods.

In 2006, there was an extended drought throughout the US growing area resulting in virtually no subsoil moisture prior to planting. In Uvalde, there was only 2.8” of rain in 12 months through PM in an area that averages 30”. There were no planting rains for the rainfed crops, and the only fields that performed close to average were those where there were good pre-plant irrigations. Once the sesame germinated, there was a dry line below the roots that prevented deep penetration. Trying to get the dry soil below wet, the irrigations hurt the sesame more than they helped. Fields with fewer irrigations of around 1” per irrigation had higher yields than fields with more irrigations of around 1.5” per irrigation.

### **Wind**

In any breeding programs, wind should be taken into account because of the potential of lodging. In the last 10 years of the US sesame program, through constant selective pressure, lodging has been a rare problem that usually occurs only when winds exceed 40 MPH. In the 2006 northern Texas Sesaco nursery, less than 1% of the plants lodged with two days of winds between 30 and 55 MPH.

- During the germination stage, wind is rarely a problem except for hot continual winds that can pull the moisture out of some soil types. If the

farmer does not plant deep enough, the moisture around the seed can evaporate and prevent germination. However, planting deeper to prevent this problem will take the seedling longer to emerge.

- In the seedling stage, the wind can cover the seedlings with blowing dirt and sand. While seedlings covered by rain carrying silt will seldom push through, the silt from wind is looser and occasionally, the seedlings can push through and survive. Normally, the seedlings are low enough to have a low profile to the wind, and there is no lodging at this point. However, in windy areas such as northern Oklahoma and Southern Kansas, the winds can whip the seedling around and the stems will form a cone into the soil. There has been no apparent damage from this, and in fact, this may help the stem develop more wind resistance.
- In the vegetative phase in many areas of the West Texas, where the soils are sandy, farmers need to ‘sandfight’ on all of their crops. Rains create the problem in sandy soils by slicking the ground. Winds can then carry sand that blasts the tender seedlings and depending on the intensity, can just shred the leaves and set the seedlings back or can ‘sandpaper’ the plants to just stems. If there is a need to sandfight for cotton, there is a need for sesame. As soon as farmers can get a tractor into the field, they will till the soil with an implement to trap the sand. Normally, one month after planting, the plants are tall enough not to require sandfighting.
- During the reproductive phase, although it is rare, wind can blow flowers off the plant. This tendency to blow off is genetic in terms of the strength of the pedicel.
- Generally, the leaves act as shock absorbers and branches and plants rubbing against each other in the wind do not lose their capsules; but in the ripening phase as the plants lose their leaves, the capsules come into contact, and the capsules can rub off. Triple capsules rub off more easily than single capsules.
- In the drying phase, the capsules will open and winds can cause the seed to shake out of the capsules. Although the amount of shatter resistance is the largest determinant of the amount of seed lost, the architecture of the plant can make a difference. The tips of branches whip the most and are more apt to lose seed. With improved non-dehiscent capsules, there is less loss in the tips of the plant as shown in Photo 39.



- Winds can be beneficial in the drying phase in that they pull moisture out of the plants faster. Once the plants are dry, the wind, in conjunction with low humidity, can increase the number of harvest hours per day.
- After the seedling stage, the main peril from wind is lodging. In understanding lodging, it is important to realize that the stage and plant architecture can create different amounts of wind resistance. The following characters present more resistance: tall plants, large leaves, branches, wide angle branches, and three capsules per leaf axil. The weight of the plant also makes a difference once the winds start bending the plants. Wet plants from rain tend to lodge more than dry plants. There are three types of lodging: plants breaking at the stem, plants bending over but not breaking, and plants uprooting and bending over. When a plant breaks over, it will rarely produce any new seed, and the existing seed may or may not mature. If there is a total break, there is no hope, but if there is still some active stem translocation through the break, there can be some yield recovery. The main causes for uprooting of plants are shallow root systems and fields that have just been irrigated, creating a soft layer of soil.
- Present varieties are shorter, have smaller leaves, have narrower angles on the branches, and have a single capsule per leaf axil. This architecture lowers the wind resistance, and there are fewer lodging problems than there were with earlier varieties.
- When a plant bends over early in development, some lines adapt better than others in terms of having the main stems turn up and continue flowering. The tips of the branches are usually matted under the canopy and will rarely turn up, but new branches can develop. As the plants go to drydown and the weight of the moisture is lost, many of the bent plants will straighten up, making the crop easier to combine. Fields that lodge in the early reproductive phase have a much better chance to recover than later lodging.

### Temperature

The rule of thumb is that 150 frost free days are needed for sesame (Kinman and Martin 1954). Work has been done in the greenhouse on optimum temperatures, but the conditions cannot approximate the interactions between temperature, sunshine, and wind in the field. Many publications have repeated that temperatures above 104°F affect fertilization and seed set (Weiss 1971) implying that sesame crops should not be grown in hot areas; however,

excellent crops have been grown in Arizona where the day temperatures during the reproductive phase are rarely below 104°F and often reach 120°F.

On the cold side, as stated earlier, low temperatures can prevent or inhibit germination; will lead to slower growth; and will slow down ripening. In the US, there can be frosts at the end of the cycle. Planting on time will normally keep the crop from frosts through the full maturity stage, but after that point, frosts are possible and are an advantage. Frosts can accelerate the drying phase, which moves harvest into a better weather window.

In learning the latest time to plant, there were many commercial fields that had a frost or even a hard freeze. In the 1950s, a crop in Kansas had a hard freeze near maturity and the plants dried down quickly. The seed was harvested and appeared to be fine; however, within a week, the seed was rancid. M. Kinman (pers. commun.) watched the harvest, tested the seed, and found extremely high acid values. He speculated that the freeze created ice within the seed. The temperatures and length of time below freezing were not recorded. Since that time, there have been several hard freezes around 25°F for as much as 6 hours during the drying phase. There was an accelerated drydown, but the harvested seed was not damaged. However, there has not been a freeze when the seed contains high moisture (60% at physiological maturity). Dry seeds placed in the freezer for weeks have germinated.

The effects of frost are difficult to determine because conditions vary too much to compare frosts. In general, a frost may accelerate a drydown, and it appears that at the same temperatures, crops further along on drying will be affected more than crops that are still green. In one extreme case, a line from Paraguay that was still flowering continued flowering after a frost that dried down the other 1,100 lines that were still green.

In 1998, an extreme abnormal frost hit Oklahoma and north Texas in mid September – seven weeks before normal early frosts. Most of the fields were still flowering, but there were no general patterns – some fields stopped flowering and others continued flowering. One interesting effect was that in most fields, the leaves on the side of the wind dried down. This was a repeat of the observation in a late planted field in 1990, where the ambient temperatures were above

freezing but below freezing with the wind chill factor.

Vernalization (subjecting seeds to low temperatures) is not needed for sesame to germinate. Given the right temperature, sesame seeds can germinate once they are dry. There are a few cultivars of sesame in the world (Cola de Borrego in Mexico and UB1 in Thailand) that have a seed dormancy that is broken by time.

## Hail

The sesame growing areas in the US are prone to hail storms. As with any crop, if the hail is severe, it can destroy the crop. However, the present US varieties of sesame have good recovery traits. There is sesame germplasm that will not branch under any circumstance, including losing the growing tip on the main stem. This type of germplasm has been eliminated from the US program because of the problems with hail. Within branching lines, there are differences in the amount of branching in terms of the number of branches and the percentage production of seed on the branches. Branches are important in hail damage because the growing shoot of the main stem is tender and a direct hit will often break the tip off. Unless branches start, the production of that particular plant is stopped at the point of the hail strike.

The effect of hail on the phenology depends on development stage of the plant. In the vegetative phase, the hail may lengthen the phase as much as a week, whereas in the later phases, it will shorten the phase. Given a hail of equal intensity, the earlier the damage, the higher probability of recovering from the damage.

- In the seedling stage, if there are no first leaves and the head of the seedling is severed, the plant will die. If the first true leaves are severed, the plants will form branches from where the cotyledons meet the stem. Above the first set of leaves, there will be branches commensurate with the amount of light and the number of node pairs available to form branches.
- In the rest of the vegetative and early reproductive phase, in moderate to high populations, the dominant plants will get the hail hits and damage, and often the minor plants will grow through the canopy and become the dominant plants. If the hail hits the primary meristem, the optimum situation is to have it break off entirely. Often the top is broken over and hangs on the plants. The plant tip will bend up and will flower and set capsules, but with the reduced flow of fertility, there will not be much seed produced. However, the worst effect is that the primary meristem appears to suppress the secondary meristems,

and these plants will not have substantial branches. In some years, the severity of the damage is not seen until harvest when there is lower yield. In extreme cases, the leaves have been torn apart, but the plants have gone on to branch and produce flowers and capsules; however, the reproductive phase is delayed.

- Sesame leaves are soft and hail will easily go through leaving minor holes. A single hail stone can damage multiple leaves. If there are enough hail stones, the hail can reduce the leaf surface area. Hail hitting the stems will leave “bruises” – darkened areas.
- In the reproductive phase, hail can damage the leaves enough to reduce the rate of flowering but will actually extend the date to flower termination. However, if the leaves are severely shredded, the plants may stop flowering. Although the stem and capsules are green, they do not produce enough photosynthesis to fill the seeds. The plants will delay going to physiological maturity.
- In the ripening phase, there are fewer leaves and the capsules are more exposed. The hail can have a direct hit on a capsule and open it, taking it to drydown ahead of capsules below it. The hit can break the capsule down, but it will often stay attached to the plant and dry down. A severe hail will denude stems of the capsules and may break off parts of the main stems or branches.
- In the drying phase, dry capsules are open and have a brittle attachment to the stem. Direct hits can detach the capsule or shatter out the seed.

## Salinity

Sesame is more sensitive to salt than most crops, including cotton and alfalfa. At some point, the salinity will prevent germination, but this subject has not been studied sufficiently. Salinity slows down growth and makes the plants more yellow. In Arizona, there were irrigated fields where the sesame would thrive near the head of the ditch but would not grow near the tail-water. In these areas, the water was from the Colorado River, which was fairly salty. In 1987, different lines were planted in 8 row strips in a field where cotton and alfalfa would not grow in the west fifth of the field, due to salinity. There was as much as 30 meters difference in how far out into the salty area some sesame lines would grow, indicating genetic variability.

Peril	Distribution	Frequency	Extreme	Stage(s) affected	Crop lost (%)	
					Typical year	Extreme year
Drought	Localized	Most years	2000-2002	Any stage	1-5	30 affected but not lost
Prevented planting (due to lack of rain on non-irrigated crops)	Localized	Most years	1996, 1997	Germination	<1 to 3	15-25
Excessive heat	General	Annually		All stages	≅ 0	≅ 0
Heavy rain (at planting). Can be replanted.	Scattered	Annually		Germination, seedling	1-3	5
Excessive rains (causing lakes)	Localized	Annually	1989, 2003	Any stage	<1	3
Rain at harvest	General	Most years	2000	All of the drying phase	0-5	30 in 2000 only
Unseasonably cold	Localized	Some years	1998	Late bloom	<1	2-4
Frost	Localized	Annually	1998	Late bloom	1-2	15 affected but not lost
Hail	Isolated	Annually	2003	Any stage, more affected the later the stage	<1	2
Wind	Scattered	Annually		Before juvenile	<1	1-2
	Scattered	Annually		After juvenile	<1	1-3
	Localized	Annually	2003	Drying	<1	1-3

Table 8. Effects of weather perils between 1988 and 2003 in Texas, Oklahoma, and Kansas. In 2000, there was a period of 3 weeks with heavy dews, fogs, cloud cover, and little sunshine. All of the crops, gardens, lawns, and forests developed a fungus that covered the vegetation. Up until that point, the sesame and other crops were harvested, but after that point, all crops were abandoned. Oklahoma State extension personnel said that there had been no previous record of this phenomenon, and it has not repeated.

### Effects of weather perils

The paragraphs above detail many of the perils from weather, but sesame withstands weather very well. The Risk Management Agency of the US Department of Agriculture funded a study of sesame, which provided the information shown in Table 8 (Anon 2004).

As can be seen, sesame is a survivor crop, even in modern agriculture, as it has been over the past 7,500 years in subsistence farming in many areas of the world.

### ANOMALIES

#### Regrowth

Certain lines have a propensity for restarting growth after the main stem has stopped growing. Regrowth usually occurs in areas where conditions are such that the plants have run out of moisture and/or fertility. If there is rain, some lines will form branches at the bottom of the plant, and these will flower and set capsules while the main stem and the older branches will not start flowering again. Regrowth is considered an anomaly and is not considered as part of the typical phenology. However, it can cause confusion in that the end of mid bloom is defined

as no flowers on the branches. Regrowth and the destruction of the apical meristem (insects or hail) are the only cases where the flowering on the branches extends beyond than the flowering on the main stem.

There are three types of regrowth: top (restarts at the tops of the main stems), middle (branches emerge from the middle of the main stem), and bottom (branches start in the axils of other branches or below the branches). There are lines that show spontaneous branching whereby branches start in the middle of the capsule zone under capsules. However, this is not considered regrowth because spontaneous branches start during flowering and stop flowering before the top of the main stem stops flowering. In regrowth, the plants look indeterminate in that the lower capsules dry while the plants are still flowering.

The onset of regrowth needs further study because there are conflicting patterns. In 1991, there was a drought in a rainfed nursery from planting time, which stopped flowering in all but a few lines. With a rain, all the lines that had stopped went into regrowth. In a 2006 rainfed nursery, there was a drought resulting in no flowers on most lines, and yet after a rain, the plants started flowering again without going to



regrowth. The lines flowered longer than normal, but the lower capsules did not dry down while the plants were flowering. In some years, lines with a tendency to go to regrowth will be the only lines to go to regrowth, and yet under similar conditions, none may go to regrowth. To date, no line has been found that will not go to regrowth under the proper conditions. Fields will rarely go to regrowth in cooler night temperatures.

### **Vivipary**

Under some conditions, there is vivipary in sesame – the seeds will germinate in the capsules. Not only are the germinated seeds lost, but the roots of the seedlings bind the rest of the seed. Many farmers have felt that the opening of the capsules allows water to enter and germinate the seed. Actually, the opposite occurs. Seeds in open capsules do not germinate because the moisture will evaporate out of the capsule before the seed can germinate. The vivipary occurs in closed capsules. It is believed that this is a dispersal mechanism to open the capsule and allow the seed to fall out. Vivipary is controlled genetically with some lines having a greater propensity than others. Vivipary is rare in the US because normally at harvest the temperatures are below 70°F – the minimum germination temperature.

### **Glyphosate drift damage**

With the advent of Roundup Ready crops, there is a lot more spraying of glyphosate near sesame fields. When glyphosate drifts on to sesame,



Photo 42. The farmer sprayed glyphosate to the field next to this sesame field, and there was some drift. There are plants missing 1 to 10 node pairs. These plants are flowering longer and will take longer to dry down. depending on the amount of chemical, there will be 1 to 10 node pairs that will not set capsules

(Photo 42), and there will be a lot of sterile seeds in the capsules below and above the capsule gap. When there is a substantial amount of chemical, there may be a kink in the stem and there may be spontaneous branches at the top. These plants will flower longer than the rest of the crop and the greener plants will be very visible at then end.

The problems are even more apparent when the plants have lost their leaves and have dried down (Photo 43).



Photo 43. The two outside plants are from the part of the field not affected by the glyphosate, and the other 3 plants show the capsule gaps. Note the greener tops and the plants bending where the glyphosate affected the plants. This type of damage can be seen regularly in cotton areas with the new flex varieties that allow continual spraying.

### **Fasciation**

It is rare but eye-catching to see a flat stemmed plant with many capsules (Photo 44). This plant has had a malfunction, and seed harvested from this plant will produce normal plants the next year.



Photo 44. Fasciated plant.

### **Insect or hail damage**

When an insect or a pellet of hail destroys the growing point on the main stem, all of the leaf axils have the capability of putting out branches that will

be productive, as shown in Photo 43. This response is critical in that there is germplasm that will not put on branches and there is no more seed production on that plant.



Photo 43. This plant had the tip bitten off by an insect, but the response of losing the growing tip to hail is similar in that the plant will put on branches and will flower and set capsules.

## SESAME IN THE REST OF THE WORLD

Although sesame is a relatively new crop in the United States, it has been grown for over 7,500 years in Asia and Africa. As shown in Table 9, there are 3,740,000 short tons of sesame produced in the world. The data is derived from the United Nations (<http://faostat.fao.org/>). The production data is available one year after actual and the trade data two years after actual. The data is updated each year on the American Sesame Growers Association (ASGA) website (<http://sesamegrowers.org/>).

Area	Harvested acres (000)	Production (000 tons)	Imports (000 tons)	Exports (000 tons)	Consump (000 tons)
Asia	11,476	2,434	749	409	2,774
Africa	6,549	1,076	39	463	652
Europe	1	1	145	23	122
North America	0	0	54	3	51
Central America	240	60	43	57	46
South America	604	169	5	90	84
Oceania	0	0	8	0	8
World	18,870	3,740	1,042	1,046	

Table 9. World production (CY 2006) and trade (CY2005) figures based on the FAO data.

The growth and development of sesame in the rest of the world is very similar to the US as described in the previous pages, but in the rest of

the world, the sesame is all harvested during or at the end of the ripening phase. There is no drying while the plants are still standing in the fields. Over 99% of the harvest in the world involves some or total manual labor. Due to the shattering nature of the capsules, the sesame needs to be cut when it is green and shocked so less seed will fall out as the plants dry. Even in shocks, if there is rain, there can be as much as 50% loss. Photos 45-54 show some of the harvest practices in the rest of the world.



Photo 45. In Paraguay, plants are cut while still green and with leaves.



Photo 46. The plants are then placed in a shock to dry.



Photo 47. In India, the farmers manually thresh the seed over a sheet or plastic. Photo by N. Smith.





Photo 48. Cleaning is done by winnowing – letting the wind blow the chaff away. Photo by N. Smith.

There are very few countries where there is any mechanization at all. In Korea, China, and Thailand, there are some tractors and planters. Farmers are also adopting rice equipment to cut the sesame and thresh it. In some cases, rice combines are being used.



Photo 49. In Korea, most of the sesame is planted on beds with vinyl covering for weed control and earlier germination (raises the soil temperature). In some areas, the plants are cut with a rice cutter and then shocked. Photo by C. Kang.



Photo 50. When dry, the shocks are moved to stationary threshers. Photo by C. Kang.

In Venezuela and some areas of Paraguay, there is cutting with binders and then combining of the shocks.



Photo 51. In Venezuela, the sesame is opened by manually cutting the sesame until wide enough for a tractor with a side attached binder. The bundles out of the binder are left for a day to dry and then shocked.



Photo 52. In Venezuela, when dry, the stalks are cut and a combine fitted with a locally designed attachment pushes the shocks into augers that feed the combine.

In Mexico, there is manual cutting and combining the shocks. In Australia, there is some direct harvest after applying Reglone as a desiccant, but there has been so much loss at harvest that there are few farmers still growing sesame. Venezuela tried the desiccant and direct harvest but abandoned the practice.

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