Progress in Mechanizing Sesame in the US Through Breeding

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OVERVIEW

Sesame (Sesamum indicum L. Pedaliaceae) is one of the oldest crops known to humans. There are archaeological remnants of sesame dating to 5,500 BP in the Harappa valley in the Indian subcontinent (Bedigian and Harlan 1986). Assyrian tablets from 4,300 BP in a British museum describe how before the gods battled to restore order to the universe, they ate bread and drank sesame wine together (Weiss 1971). Most people remember the words “Open sesame” from Ali Baba and the 40 Thieves used to open a cave full of riches. It is similar to the sesame capsules in that their opening produced great riches. Sesame was a major oilseed in the ancient world because of its ease of extraction, its great stability, and its drought resistance. In India today, almost as in olden days, a farmer can take his crop to an expeller that consists of grinding mortar and pestle stones driven by a bullock. He can place the oil in a vessel, take it back to his home and have cooking oil for a year without the oil going rancid (S.S. Rajan, pers. commun.).

The origins of sesame are still debated. Kobayashi (1986) suggested that sesame originated in Africa, but Bedigian et al. (1985) concluded that sesame originated on the Indian subcontinent. Ashri (1998) felt that settling the debate on the origin of sesame will require more detailed cytogenetic and suitable DNA comparisons. From whatever origin, sesame spread into Africa, the Mediterranean and into the Far East. In the Middle East a tremendous amount of sesame is consumed as tahini (sesame butter or sesame paste). Tahini mixed with ground chickpea kernels becomes hummus. In China, Japan, and Korea, sesame is used widely as a cooking oil, and it is consumed for its medicinal qualities. In these countries, grandmothers advise, “Eat sesame for health.” (M. Namiki, T. Osawa, C.W. Kang, pers. commun.). In recent years the Japanese have been identifying and quantifying the medicinal benefits of sesame. In vitro and animal studies have verified several antioxidant properties (Namiki 1995), and initial unpublished results in human studies further verify that stories passed down through generations have merit (M. Namiki, pers. commun.). In the West, sesame is primarily used in the confectionery trade in rolls and crackers. Throughout the world, sesame seeds or paste are mixed into sweets, esp. halva. Sesame oil use in the cosmetic industry continues to expand. In India sesame is used in many religious ceremonies (Joshi 1961).

There are many publications that provide an overview of sesame and breeding strategies, and most of that information will not be repeated in this paper. D.G. Langham and Rodriguez (1945) provided much of the initial thinking on mechanization. Weiss (1971, 1983, 2000) provided a good introduction to sesame; the latter two publications have more recent information, but the 1971 publication is longer and has more detail that is still pertinent. Ashri (1998) summarized most of the recent breeding and genetics work and includes information from the discussions at many FAO, IAEA, and IDRC sesame conferences. Beech (1985) and Beech and Imrie (2001) have been working on introducing sesame in Australia and their discussions on his ideal plant type are very relevant to cultivar development in general whether it be for manual or mechanized harvest. Mazzani (1999) reviewed many of the aspects of the Venezuelan sesame development program. The present paper will provide some updated information and will primarily address the characters that are important in the machine/plant interface as elucidated in the extensive breeding program of Sesaco Corporation (San Antonio, Texas).

SESAME VARIABILITY

Sesame is a plant breeder’s dream because it has so much variability. In many parts of the world, farmers have not been touched by breeder-developed sesame. In 1967 in one field in Rajasthan, India, the first author found over 22 phenotypes. Bedigian and Harlan (1983) found that cultivars changed from village to village in the Sudan. In Korea there has been an aggressive breeding and extension program to introduce improved cultivars, but in 1997, 29% of the sesame were still local cultivars (Kang 2001). In 1999, in a journey around the perimeter of South Korea, the first author saw tremendous variability. Commercial seed samples from China show great variability as each farmer delivers his 1–10 bags of sesame to the local collec-
tion point. In 1999 in Venezuela, where reportedly only two cultivars were grown, the first author collected 11 different phenotypes in one farmer field.

Sesaco has studied 412 characters in terms of range of variability and commercial implications. Characters are added to the list each year as additional introductions are examined. For example, after a rain, it was noted that one line from Iraq had raindrops on the leaves that resembled the raindrops on a recently waxed car. This line is one of the most drought resistant lines, perhaps due to a waxy cuticle on the leaf. India (Bisht et al. 1999), China (Xiurong et al. 1999), and Korea (J. Kang, pers. commun.) have excellent programs to collect the local germplasm, preserve it, and to form core collections. Sesaco presently has a collection of 2,738 introductions from 66 countries (D.R. Langham 2001a). Many of these lines were acquired from the Plant Genetic Resources Conservation Unit, S9 of the USDA, ARS, National Plant Germplasm System (NPGS). This latter collection has a tremendous number of unique genes and is accessible on the internet (www.ars-grin.gov). It presently has 869 available accessions from 41 countries (Morris 2002). IPGRI maintains large duplicate base collections assembled by Ashri in the gene banks in S. Korea and Kenya (Ashri 1994). The Japanese have also established a germplasm bank accessible on the internet (www.gene.affrc.go.jp). Using the introductions as a starting point, Sesaco has evaluated 33,545 cross combinations to develop the current cultivars.

Another reason sesame is a plant breeder’s dream is because the architecture has not been set in stone. Many of the plant breeders and farmer selectors have different views of the ideal architecture, and certainly the diverse environments have an effect on the chosen architecture. Looking at only 7 characters (branching style, number of capsules per leaf axil, plant height, internode length, capsule length, number of carpels, and maturity), it is possible to visually identify lines developed by 6 major breeders: D.G. Langham (Venezuela and Sesaco), M.L. Kinman (USDA, College Station, Texas), D.M. Yermanos (University of California at Riverside, California), T. Kobayashi (Japan), C.W. Kang (South Korea), and W. Wongyai (Thailand) and from 7 major regions: Korea/Japan, China, Myanmar/Thailand, India/Pakistan, Middle East/Turkey, East Africa, and South/Central America.

Sesaco has planted its major nursery in Uvalde, Texas (latitude 29°22’ north, 226 m elev.) in middle to late May from 1988 to 2001. The mean rainfall is 608 mm annually with a mean of 253 mm during the growing season (the nursery is irrigated). Temperatures range from an average low of 3°C and average high of 17°C in January to an average low of 22°C and high of 37°C in July. Other nurseries are planted in West Texas and Oklahoma. The data in Table 1 shows the variability of sesame in Uvalde.

There are lines varying from tolerant/resistant to extreme susceptibility to drought, root rots (Fusarium oxysporum, Phytophthora parasitica, and Macrophomina phaseoli), bacterial leaf blight (Pseudomonas sesami), green peach aphid (Myzus persica), white fly (Bemisia argentifolium and B. tabacci), cabbage looper (Pieris rapae), and army worm (Cupis unipuncta).

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. 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 (Sesaco collection), protein from 19% to 30% (Ashri 1998), oil from 34.4% to 59.8% (Ashri 1998), oleic acid from 32.7% to 58.2% (Yermanos et al. 1972 and Japanese germplasm database), linoleic acid 27.3% to 59.0% (Yermanos et al. 1972 and Japanese germplasm database), sesamin 1.6 (Namiki 1995) to 11.3 mg/g of oil (Beroza and Kinman 1955), and sesamolin 0.1 to 8.6 mg/g of oil (Japanese germplasm database). One of the unique aspects of sesame protein is the high content of methionine. In addition to the sesame lignans identified in the 1950s, recently the Japanese have identified sesaminol, and they are looking at sesaminol glucosides. The latter are significant because they are water-soluble and travel with the meal whereas the lignans are oil soluble and travel with the oil. As a result, the meal when processed as flour, has also shown stability due to antioxidants. In discussions at the 1999 AOCS Sesame Symposium in Orlando, many of the researchers felt that based on the stability of the oil, there may well be other components that are yet to be discovered. In particular, Japanese research teams are focusing on black sesame cultivars which appear to have different qualities.
Table 1. Variability of sesame lines in Sesaco nurseries in Uvalde, TX.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant height</td>
<td>67–245 cm</td>
</tr>
<tr>
<td>Height of first capsule</td>
<td>25–150 cm</td>
</tr>
<tr>
<td>Capsule zone length</td>
<td>18–120 cm</td>
</tr>
<tr>
<td>Number of branches</td>
<td>0–20</td>
</tr>
<tr>
<td>Height of first branch</td>
<td>2–135 cm</td>
</tr>
<tr>
<td>Number of nodes on main stem</td>
<td>4–65</td>
</tr>
<tr>
<td>Internode length at middle of capsule zone</td>
<td>1–11 cm</td>
</tr>
<tr>
<td>Mean internode length for whole capsule zone</td>
<td>1.9–8.0 cm</td>
</tr>
<tr>
<td>Leaf length (5th node from base)</td>
<td>11.7–31.0 cm</td>
</tr>
<tr>
<td>blade length</td>
<td>2.1–23.6 cm</td>
</tr>
<tr>
<td>petiole length</td>
<td>4.5–20.0 cm</td>
</tr>
<tr>
<td>Days to 50% flowers</td>
<td>28–98</td>
</tr>
<tr>
<td>Days to 90% flower termination</td>
<td>51–133</td>
</tr>
<tr>
<td>Flowering period</td>
<td>10–98 days</td>
</tr>
<tr>
<td>Days to physiological maturity (PM)</td>
<td>70–167</td>
</tr>
<tr>
<td>Days to first dry capsule (DC)</td>
<td>74–180</td>
</tr>
<tr>
<td>Swathing window (PM-DC)</td>
<td>−14 to 28 days</td>
</tr>
<tr>
<td>Number of capsules per leaf axil</td>
<td>1–7</td>
</tr>
<tr>
<td>Number of locules</td>
<td>2/4/6/8</td>
</tr>
<tr>
<td>Capsule length</td>
<td>1.3–7.0 cm</td>
</tr>
<tr>
<td>Seed loss at drydown</td>
<td>0–100%</td>
</tr>
<tr>
<td>Seed weight/capsule</td>
<td>0.08–0.48 g</td>
</tr>
<tr>
<td>Capsule weight/capsule</td>
<td>0.07–0.37 g</td>
</tr>
<tr>
<td>Capsule harvest index</td>
<td>36–72%</td>
</tr>
<tr>
<td>Seeds per capsule</td>
<td>30–120</td>
</tr>
</tbody>
</table>

*Generally one of the largest leaves on the plant.

SESAME STATUS

All of the production and trade data that follows was taken from the FAO website as of Feb. 2002. In 2000 the area of sesame harvested in the world was 7,407,226 ha, and the amount of seed produced was 2,941,290 tonnes (t) for an average of 397 kg/ha. There were 588,586 t of sesame imported. Fig. 1 shows the changes in production and imports between 1961 and 2000. The area grown has increased by 149% and production by 207% due to higher demand for sesame imports which have increased by 550%.

In 2000 the major producers (in 1000 t increments) were China (812), India (542), Myanmar (296), Sudan (282), Uganda (97), Nigeria (69), Pakistan (51), Bangladesh (49), Ethiopia (49), Tanzania (42), Mexico (41), Thailand (39), Central African Republic (38), Egypt (37), Venezuela (32), and Republic of Korea (32). Fig. 2 shows the top 5 producers between 1961 and 2000. Most of the sesame acreage is grown under rainfed conditions and is very dependent on moisture. In any given year, the production can vary up or down depending on rainfall. The increase in production in China is due to improved cultivars.

In 2000 the major importers (in 1000 t increments) were Japan (165), Egypt (86), Republic of Korea (70), and the US (49). The importance of the Near East and Europe is magnified when the small countries are aggregated. Fig. 3 shows the imports into Japan, the Near East (including Egypt), Europe, Republic of Korea, and the US between 1961 and 2000. While the imports into the US have been gradually increasing, the other areas have increased imports dramatically in the last 15 years. In Korea, the price of sesame to the consumer is 10 times greater than the world market due to a combination of price supports to the farmers and import
Trends in New Crops and New Uses

tariffs (C.W. Kang, pers. commun.). It is anticipated that when these artificial measures are lifted, the consumption in Korea will increase dramatically.

In 2000 the major exporters (in 1000 t increments) were India (183), Sudan (139), China (103), Nigeria (35), and Ethiopia (31). Fig. 4 shows the exports of the top three countries and Central America (including Mexico) between 1961 and 2000. India has become the largest exporter even though in the past there were many pesticide residue issues with Indian seed. Although China has played a major role in the export market, some traders predict that China will become a net importer in the next 10 years as consumption increases. The influence of Central America has fallen considerably since its peak in the early 1980s as production has fallen. The total exports from Central America overstate the importance since in the past 5 years some of the seed they exported was imported from Sudan and India, dehulled, and then re-exported. Similarly, south China imports some sesame while northern China exports it. Fig. 5 shows the net exports.

Although the production in the world has increased, the production is virtually non-existent in countries with mechanized agriculture. The area in sesame has decreased in traditional sesame growing countries such as Japan, the Near East, Korea, and Mexico where there is increased mechanization. The mantra has always been that the developing countries have such cheap labor. However, the trends are clear. As youth in rural areas move to cities for better opportunities, hand labor is moving to high margin crops such as vegetables. Field crops that cannot be mechanized are being replaced by those that can. Speaking to farmers in Guatemala, Korea, Venezuela, and Thailand, it becomes clear that the cost of manual labor is increasing and cutting into margins already being reduced by lower world sesame prices. In many areas of the world, the trend of subdividing farms as they are passed down through generations is being reversed as successful farmers acquire neighboring land to increase farm size and are mechanizing.

In several international meetings, the first author has made a very controversial prediction: unless sesame is mechanized in the next 25–50 years, its world production will decrease significantly. Without mechanization, sesame will only persist in those niches where no other more suitable crop can be grown.
Sesame was introduced to the US from Africa and was called beni/benne/benni. Betts (1999) quotes letters from Thomas Jefferson that document his trials with sesame between 1808 and 1824. Jefferson stated that sesame “…is among the most valuable acquisitions our country has ever made. … I do not believe before that there existed so perfect a substitute for olive oil.” He talks about the rule of thumb that still exists today—that sesame will do well where cotton does well.

In the 1940s research was begun in South Carolina (Martin 1949), Nebraska (Hoffman 1949), and Texas (Kalton 1949). Sesame did not advance much in South Carolina, and Nebraska was too far north for sesame. In Texas in the 1950s sesame became a viable crop in West Texas and by the mid 1960s there were over 4,000 ha (R. Parker, pers. commun.). In the USDA, M.L. Kinman, T. Culp, G. Rivers, and C. Thomas had very aggressive breeding and agronomic research programs planting sesame in experiment stations throughout the US. E. Collister in Texas released cultivars from the Renner Foundation (pers. comm.). When the hand labor from Mexico became unavailable, the sesame crop disappeared. D. Yermanos tried to establish sesame in California and D. Rubis in Arizona, but no significant area was grown (pers. comm.). Texas A&M continued with the Kinman germplasm and some progress was made by E. Whitely, G. McBee, O. Smith, R. Brigham, J. Mulkey, J. Grichar, and D. Smith (pers. commun.).

In 1978 Sesaco was established to bring D.G. Langham’s work from Venezuela to the US. It was clear that in the US, complete mechanization would be necessary, and by 1982 the first mechanized cultivars were released in Arizona. Sesame area reached about 3,500 ha in Arizona before the crop was displaced by vegetables. The company moved to Texas in 1991. Since that time 6,000 to 12,000 ha have been grown annually, depending on rainfall at planting time, in Texas, Oklahoma, and Kansas. Yields for irrigated fields range from 900 to 1900 kg/ha and for dryland (summer rains) between 340 and 1350 kg/ha. Yields are highly dependent on the amount of soil moisture and fertility and the planting date.

**HARVESTING**

At present, over 99% of the sesame in the world is harvested manually. Weiss (1971) provides an excellent description of the myriad of harvest methodologies throughout the world. In general, the mature plants are cut, bundled, and shocked to dry. In some areas the shocks are left in the field. In other areas the bundles are moved to a shocking fence (as in parts of Africa) or to a threshing floor (as in parts of India). As the plants dry, the capsules open and some of the seed can fall out. If on a threshing floor, the shocks can be moved every few days, and the seed collected. If in the field, the fallen seed is lost. Noting the 397 kg/ha world
average, it reflects the seed saved and not the seed produced. While opening capsules in shocks, the first author has found that in some areas of the world, as much as half of the seed can be lost during drying.

Although the obvious solution would be to have a capsule that does not lose its seed, increased shatter resistance can be a problem. In the threshing, the farmers invert the bundles and hit the stalks, and the seed falls out. This is very physical work, and the last thing that the farmer wants is a capsule where the seed will not fall out with a couple of good jolts. Opening each capsule to release all of the seed would be too time consuming. Thus for millennia, mutations that did not release their seeds were discarded by the farmers or did not pass their seeds to the next generation because they did not fall out.

There is a limited amount of mechanization in some countries. In Venezuela, the fields are manually cut to open space for tractors. The plants are then cut with a binder, manually shocked, and then combined mechanically. Some farmers manually pitch the shocks into the combine while others use an ingenious device to slam the shock into an auger that feeds it into the combine. A limited amount of the crop area in Australia is combined directly after spraying the crop with Reglone to desiccate the plants, but there is still a tremendous amount of shattering and loss of seed. Reglone was tried briefly in Venezuela, but abandoned because the yields were not superior to traditional methods, and the quality of the seed was not suitable for the market. In Thailand and Korea, some innovative farmers cut the sesame plants with rice cutters, still shock the sesame, and move the sesame to stationary thresher.

Korea has a government support price for sesame far above the world price. As a result, Korean farmers invest much more time in their sesame fields. C.W. Kang (pers. commun.) determined that 1,255 man-hours/ha were used for growing sesame with all manual labor. With some mechanization the hours were reduced to 247 hr/ha. In Venezuela the estimates are 7.65 hr/ha (L. Jimenez, pers. commun.).

**United States**

In the 1950s and 1960s sesame in the US was harvested using the same technology as Venezuela—cutting, binding, shocking, and combining. Later in the program, M.L. Kinman began experimenting with swathing and leaving the sesame to dry in windrows.

When Sesaco began the program in 1978, the concept was that in the Arizona desert, the water could be cut off and in the heat the plants would dry down quickly allowing direct harvest. Over 90% of the seed was lost. The next concept was to develop a machine that would go through the field when the lower capsules were dry and shake the seed into trays to feed a bin. Although initially promising, one night a wind hit a field that was to be harvested, and the ground looked like it had snowed. The third concept was to return to the idea of swathing proposed by M.L. Kinman. The initial cultivar was adequate with a 30% loss with no rain, but could lose as much as 60% with just a little rain on the dry windrow. However, this method usually provided enough return to the growers to be economically viable. With this method, timing was important in that the capsules had to be green still to avoid large seed losses in the swathing operation. New cultivars were released with increased shatter resistance, and the seed loss was reduced. Occasionally, a farmer would try direct harvest, but it would not work.

When Sesaco began planting sesame in Texas in 1988, swathing was tried with mixed results. In Arizona sesame had been grown on flat fields that were laser-leveled. In Texas irrigated areas, the irrigation was in furrows, and upon swathing, the stems would roll into the furrows and could not be picked up. In West Texas, some of the windrows became sand dunes when the wind was strong. Fortunately, the line with the breakthrough shatter resistance (‘S11’) was at the foundation seed stage. Part of the field was swathed and part left for direct harvest. For the first time, more seed was harvested from the direct harvest.

‘S11’ was a tall cultivar, almost 2 m in height. Combines with row crop headers that were used for soybeans were marginally successful but were only available in South Texas. In West Texas the farmers tried the platform headers used in wheat with several of types of air assistance, but most were difficult to use because the farmers used different row spacing. In addition, the combine header width seldom matched the planter width further complicating harvest. The sesame plants were too tall for platform headers.

In 1997, farmers in Oklahoma planting on flat ground returned to swathing and combining. This method increased yield, and the practice was expanded into Texas. However, in 2000 weather conditions seriously degraded the quality of the swathed sesame. The purchase of field run sesame in the US is based on a system
of grades with bonuses and discounts. The farmers found that there was more net return with lower yield and bonuses than with higher yields and discounts. The only swathing that was done in 2001 was by farmers needing to clear a field to plant wheat. Presently, changes to be discussed below allow US farmers to harvest with platform headers (D.R. Langham et al. 2001).

Presently, the sesame cultivars developed by Sesaco are adapted to the Southwestern US. Sesame is a semi-tropical crop requiring around 21°C soil temperature to germinate and grow rapidly. D.G. Langham raised beautiful nurseries as far north as Connecticut, but the growing season was too short to complete the crop. Yield and early maturity are inversely proportional, and early cultivars do not produce sufficient economic return north of South Kansas. Drought tolerant sesame materials are very susceptible to high moisture, and accessions from high moisture areas such as Korea and Bangladesh are very susceptible to drought. Sesaco has chosen to breed towards drought tolerance, but the range of variability would allow development of sesame cultivars suited to the Southeast US. The drought tolerance allows sesame to be produced on one-half the amount of water required by irrigated cotton, one-third of sorghum, and one-fourth of irrigated corn. There have been many dry seasons in Texas when sesame was harvested while cotton, corn, and sorghum were plowed under.

In the US, for certain farmers who harvest direct in different farming conditions, the hr/ha required for sesame are as follows:
- Furrow irrigated South Texas: 1.57 hr/ha (B. Gilleland, pers. commun.)
- Dryland Central Texas: 0.68 hr/ha (S. Nauert, pers. commun.)
- Dryland, no till, Northern Oklahoma: 0.50 hr/ha (T. Coulter, pers. commun.)

MECHANIZATION REQUIREMENTS

In the mid 1940s, D.G. Langham and Rodriguez (1945, 1949, and pers. commun.) laid out the major requirements for mechanizing sesame: (1) the plants should terminate flowering, (2) the plants should drop their leaves, (3) the seed in the capsules should mature before the capsules open, (4) the capsules should retain their seed until the plant is in the combine, and (5) the capsules should release the seed in the combine. The first 3 requirements were solved in the 1940s and improved in the 1950s/1960s through extensive breeding and exchange of materials between D.G. Langham, M.L. Kinman, and J.A. Martin. The first three requirements will be covered briefly and the last two will be covered in more detail.

Flower Termination

In many publications sesame is classified as an indeterminate crop which will continue flowering as long as moisture and nutrients are available. As the flowering continues, the early capsules dry down, open, and lose their seed. Many lines in Asia have this character, and it is quite a problem because the plants are cut as the lower capsules open. As a result, there is a continuum from mature seed to immature seed on the plants. However, there are many lines from all parts of the world where the flowering stops. In the Western Hemisphere, from the early 1940s only lines that stopped flowering were retained in selection programs.

Leaf Drop

There are lines that do not drop the leaves at maturity, but there are many cultivars that do. This is a critical character in that if leaves go through a combine, the petioles will break apart into fragments that can be a problem in seed cleaning. From the early 1940s only lines that dropped their leaves were retained in selection programs.

Seeds Mature Prior to Open Capsules

In some sesame literature this is referred to as “delayed shattering.” In the sesame research community, there are many definitions of maturity. In most of the world, maturity is defined as the time that the first capsule begins to dry down. These farmers want to cut the plant and move it into shocks prior to that seed being lost. At first dry capsule, there is a full range of cultivars where the seed close to the top of the plant is mature to where the top of the plant is still flowering. In the late 1950s M.L. Kinman (pers. commun.) did a series of experiments where he found that if a plant was cut when the seed was mature at three-fourths of the
capsule zone, that there was little loss in potential yield. The majority of the seeds in the upper one-fourth would still mature into viable seeds. He defined this as physiological maturity (PM), and the researchers in the US have used that definition. In the early days of mechanization when sesame was swathed, the objective was to have the plant reach PM before the first capsule dried down. The time between those two points was defined as the swathing window (SW). Since that time cultivars have been developed where SW exceeds three weeks and the seed at the top is fully mature.

**Seed Retention**

As with most crops with a shattering problem, the initial objective was to find a plant where the capsule did not open on maturity. In 1943 D.G. Langham (1946) and D.G. Langham and Rodriguez (1946) found such a mutation. It was controlled by a recessive allele called the *indehiscent gene* (id). In the initial *id/id* lines, the capsules were so tough that it took a hammer to open the capsules. The id allele had a pleiotropic effect on other characters: the pistils were short and bent leading to considerable infertility; the stems were twisted; there were enations on the dorsal side of the leaves and on the flowers; and the leaves and cotyledons were cupped. The id allele was shared with breeders throughout the world, and for the next 50 years they attempted to fix the problems. Most of the problems were ameliorated except that it was still very difficult to get the seed out of the capsule. Cylinders were modified to increase the surfaces to break each capsule, but the more force that was applied, the more damage was caused to the seed that are oil rich and soft. Culp (1960) predicted that joining the *id/id* genotype with a papershell capsule gene would solve the problem. The crosses were made but the early generation seeds were put in cold storage in the NPGS at Fort Collins, Colorado, when the Kinman USDA sesame program was terminated due to budget problems. D.M. Yermanos tried to solve the problem by increasing the length of the capsule, but there was still too much damage. Sesaco restarted the Kinman germplasm that had been preserved by the NPGS, made selections, and released ‘S01’ with the papershell and *id* allele in 1982. The cultivar gave adequate yields, but the seed was too damaged for commercial sale.

In 1986, Sesaco discovered a second closed capsule trait controlled by a recessive allele termed *seamless* (gs) (Ashri 1998 and D.R. Langham 2001b). The *gs/gs* capsule had an even more papershell capsule than ‘S01’. Initially it seemed that the capsule had a single carpel with two locules, but later it was deduced that there were two carpels that did not form the false membranes to separate the locules. In the combine it was still very difficult to get the seed without damaging it. After 5 years of breeding with no improvement on quality, the gs allele was abandoned. Cagirgan (1996, 1967) discovered 4 indehiscent mutations in his Turkish populations subjected to radiation. Its phenotype is like the original *id/id* plants, but to date no testing has been done to see if it is the same allele.

The Sesaco breeding program had continued with seed retention research parallel to the *id/id* program. The first shatter resistant type released was ‘S02’ using the swathing/combining technology. ‘S02’ had about 30% seed loss in no rain, but could lose as much as 60% with a little rain on the drying windrow. By 1988, the shatter resistance level reached allowed direct harvest of ‘S11’ when the plants were completely dry. In 1995, ‘S17’ windrows lay in the fields for 6 weeks after drydown in continuing rains and only 30% of the seed was lost. In a similar scenario in 2000, ‘S24’ lost only 10%. In most fields under normal conditions, less than 5% of the seed is lost from shattering. In some fields losses are less than 20 kg/ha.

In returning to breeding for shatter resistance, there was a hidden benefit that had not been foreseen. In the US in the fall, the days continue getting shorter and cooler. The result is shorter combining periods each day; for example, in Uvalde, Texas, by late-October the combines can only run between 1 and 5 pm. When the seed is mature, it contains about 60% moisture. The seed should dry down to less than 6% moisture to provide quality seed that can be stored for 12 months. In the *id/id* and *gs/gs* capsules all of the moisture from the seeds had to migrate through the capsule walls. By opening the capsules, the moisture from the seeds and the inner part of the capsules could escape out of their tips, thus speeding up drydown. With *id/id* and *gs/gs*, if it rained as little as 5 mm while the combine was running, the combine could not re-enter the field for 3–5 days. With the shatter resistant types, combining could be resumed in 1–2 days.

The shatter resistance was developed by combining six capsule characters most of which were identified by D.G. Langham et al. (1956):
Capsule Open. The capsule should open at the tip. However, if it is too open there is a higher probability of losing seed, and if it is only slightly open, there is a potential for mold forming in the capsule. Too small an opening can also hurt seed release.

Capsule Split. The capsule should dehisce at both sutures to expose the false membrane. This character is not important for seed retention but it is critical for seed release.

Capsule Constriction. As the capsule dries, there are some capsules where the capsule walls shrink around the seed holding it in place. Constriction helps seed retention, but if it is excessive, there are problems with seed release.

Membrane Completeness and Membrane Attachment. Within the carpels there are false membranes. They should be complete and as wide as possible to provide a surface to hold the two halves of the capsule together. There is a weak adhesion between these membranes that is similar to the concept of “post-it” notes. The adhesion should be strong enough to hold the halves together before the capsules enter the combine, but weak enough to release the seed when the capsules are in the combine. There are lines primarily from Thailand, Myanmar, and China that have a hole in the membrane in the lower part of the capsule. In working towards capsule split to expose the membranes, this lower hole can allow the seed to exit. This character of a hole at the bottom has been bred out of the current cultivars.

Placenta Attachment. In some lines the seeds abscise from the placenta and in other lines they are attached. The original placenta attachment discovered in Venezuela in the 1956 weather nursery was very fragile. Yermanos (1984) felt that it was too weak to provide shatter resistance. This character had been incorporated into Kinman lines and was present in ‘S03’ and ‘S07’. Through crossing lines with different placenta attachment genes and selection pressure, the placenta attachment has been strengthened enough to hold the seed to the combine and yet release them in it.

Two other characters (no tip roll-back on the capsule and appressed position of the capsule) were important, but the traits were common to most of the lines being crossed and were not difficult to incorporate into the present cultivars.

From 1981 through 1997, Sesaco used subjective ratings to determine the amount of shatter resistance. The capsules were examined when the plants were dry enough to combine. A 0–8 rating was given based on the amount of seed still in the upright capsule on the plant. The capsule was then inverted allowing gravity to pull out loose seed and another 0–8 rating was applied. The inverted rating is still used for initial screening of material.

At the 1996 IAEA/FAO sesame meetings in Turkey, there was a consensus that an objective methodology needed to be developed. Maneekao et al. (2001) modified the Sesaco methodology by counting the seeds instead of using a subjective rating. Kang (pers. commun.) placed mature plants (not dry) in bags upside down. When dry, he weighed the seed that dropped in the bag and the seed that remained in the capsules.

Sesaco developed a different system to quantify shatter resistance (Langham 2001b). In 1997, 138 lines were tested as follows. Ten capsules were harvested when they were green but at PM. The capsules were placed upright in a jar under a heat lamp. When dry, the capsules were lifted out of the jar leaving the seed that had fallen out, and that seed was weighed. Two capsules were photographed. The 10 capsules were inverted over a pan, twirled, and dropped 3 times from 15 cm to simulate the effects of wind whipping and combines hitting the plants. The seed that dropped into the pan was weighed. The capsules were then threshed in a separate container, and that seed weighed. From weighing the three groups of seeds there was a calculation of upright shatter resistance (USR) and inverted shatter resistance (ISR).

Fig. 6 compares the USR of the introductions (51 lines) to the Sesaco developed lines (87 lines). The x-axis represents the percentage of seed retained in the capsules, e.g., 65% = 60% to 69.9%, and the y-axis is the percentage of lines that fall into that retained category. All of the introductions Sesaco used to develop shatter resistance are included in the study. The studies included the lines used in the 1997 crossing program. The USR is a significant value for sesame plants that are cut and shocked upright, but it is not significant for mechanized sesame. This test assumes that there is no loss in moving the sesame from the shocks to the threshing location, and there is no weather damage. However, in threshing in India and Guatemala, there is some seed lost no matter how carefully the workers handle the bundles. In shocks in Venezuela, the capsules on the outside of the shock can lose as much as 30% additional seed over the USR after a rain. In the USR test
Trends in New Crops and New Uses

there were 40 Sesaco lines with 100% seed retention; in the introductions, there were 2 lines over 80% with the highest line from China with 88% retention.

Fig. 7 compares the ISR for the same lines. The ISR is a significant value for the sesame plants that were cut, shocked, inverted, and struck. As can be seen, most of the seeds from the introductions fall out readily, minimizing the amount of effort for the workers. It is not known if the ISR is a significant number for mechanized sesame since there was no comparison between the laboratory and field results. It can be clearly seen that breeding led to a significant increase in seed retention.

Fig. 8 compares the USR and ISR of the major Sesaco lines from the 1997 experiment. The figure includes the years the cultivars were grown by farmers. As can be seen, the ISR has improved substantially over the years. This data shows the amount of seed retention, but retention does not necessarily equate to yield. In the years when ‘S02’ and ‘S07’ were planted side by side in Arizona, the ‘S02’ outyielded ‘S07’ when there was no rain during harvest, but ‘S07’ had higher yields when there was rain. For all farmers across all years, ‘S07’ had higher mean yields than ‘S02’.

Fig. 8 shows the problem with the USR/ISR methodology for screening for shatter resistance within Sesaco nurseries: 54 of the 87 lines had 95% or better retention. However, it was observed in the field that the shatter resistance began to break down over time. The methodology does not simulate the effect of moisture on capsules. In the field, when it rains or if there is dew, the capsules re-hydrate and close up; when they dry, they reopen. Over the 3–4 week period required for the stems to completely dry down for direct harvest, this rehydration and drying cycle can occur many times. This is a severe challenge to the adhesion between the false membranes. In the USR/ISR methodology development there were attempts to spray the capsules to simulate rain; however, mold developed, and there was no adequate replication of the degrading effects of moisture on the amount of seed retention. In view of the above, and to obtain more field relevant data, Sesaco has developed a new methodology based on leaving a nursery in wind and rain for 3 months after the crop was ready for direct harvest.

The nursery used to screen for lodging resistance was on the crest of a hill in Oklahoma, and suffered more wind damage than would normally be seen in farmer fields. Capsules were harvested at drydown and then harvested 3 months later from the same plots. Many types of laboratory shakers were examined to simulate the effects of the wind whipping the capsules against each other and against the stems. A reciprocal shaker with a 3.8 cm stroke with 250 strokes/min was selected. The earlier harvest capsules were placed in a shaker for 5 min, and the lost seed weighed; then returned to the shaker for another 5 min, and the total lost seed weighed; and finally put back for an additional 5 min and weighed. Since there was little loss in the last 5 min, the samples were not tested for a total of 20 min. Using the late harvested capsules as a baseline, it was determined that 10 min of shaking was the best-fit comparison. Further testing showed that the capsules could be harvested while they were green with mature seed or when dry without any significant changes.

Fig. 6. Comparison of upright shatter resistance (USR) of 51 introductions and 87 Sesaco lines in 1997.

Fig. 7. Comparison of inverted shatter resistance (ISR) of 51 introductions and 87 Sesaco lines in 1997.
The present methodology is to harvest 10 capsules from the middle of the capsule zone of 5 plants (2 per plant). In triple capsule/leaf axil lines, one central and one axillary capsule from the same leaf axil are taken from each plant. The capsules are dried down and then placed in the reciprocal shaker for 10 min. The seed lost is weighed, and after threshing, the retained seed is weighed. The shaker shatter resistance (SSR) is computed as follows (total seed weight–seed lost weight)/total seed weight and expressed as a percentage. This test is known as “10cap test.”

The USR/ISR data was based on tests of 138 lines using 158 samples. The SSR data in this paper is based on tests of 1,111 lines using 5,084 samples. All lines in the Sesaco crossing program are subjected to 10cap testing. Sesaco lines in the yield sample program or the accelerated development program are also subjected to 10cap testing. Fig. 9 compares the SSR between the Sesaco lines and the introductions. As would be expected, the seed retention decreased enough to distinguish the different levels of shatter resistance. Fig. 10 compares the ISR from the old test with the SSR from the new test for the major Sesaco cultivars. ‘S11’ was the first cultivar to incorporate all the shatter resistance characters, and newer cultivars have improved SSR. Fig. 11 shows the ISR and SSR of the introductions that were used as parents to develop shatter resistance. None of these parents had sufficient SSR by themselves, but through breeding and selection pressure the characters were recombined to provide SSR.

The 10cap test is much more stringent than the field conditions from the time that the lower capsules are dry to the time the plants become sufficiently dry for the combine to operate. In the field there is no serious deterioration of shatter resistance in the first 30 days after the plants are ready for harvest even in rainy/windy conditions in Texas/Oklahoma. In most years, over 90% of the sesame is harvested in this time frame. In the

**Fig. 8.** Comparison of USR and ISR in Sesaco cultivars in 1997.

**Fig. 9.** Comparison of shaker shatter resistance (SSR) of 134 introductions and 977 Sesaco lines from 1997 to 2000.

**Fig. 10.** Comparison of ISR and SSR in Sesaco cultivars from 1997 to 2000.

**Fig. 11.** ISR and SSR of major lines used as parents to develop shatter resistance from 1997 to 2000.
past 21 years rains have kept the combines out of some of the sesame fields in Texas/Oklahoma for more than 30 days in 3 years only. As mentioned earlier, in 2000, ‘S24’ only lost about 10% of its seed after 6 weeks of rain. Generally, when sesame is harvested late, it is due to low priority on the part of the farmer.

However, this more stringent test is used in selecting materials because in agriculture one of the saddest events is when a farmer gets a crop all the way to harvest and then it is lost. The current minimum requirement for a cultivar is SSR65 and this is known as non-dehiscent sesame. There are currently (in 2002) 403 Sesaco lines with SSR>64.9. It is anticipated that the minimum of SSR70 may be set in the next few years, and eventually it will be 75–80. Higher SSRs can cause problems on the release of the seed in the combine as discussed in the next section.

There is one general character that is related to seed retention. The single capsule per leaf axil lines generally have higher SSR than the triple capsule per leaf axil lines. In separating the axillary capsules from the central capsule, it was found that the central capsule had more shatter resistance than the axillary capsules. In the last two years, there have been triple lines that are non-dehiscent, and it is expected that as these lines are crossed with other triple lines, there will be adequate shatter resistance in triple capsules.

**Seed Release**

In the years of developing shatter resistance, it was critical to understand that the breeder had to ascertain that the seed was not held in the capsule so tightly that the capsule would not release the seed in the combine. The greater the force used to release the seed from the capsule, the greater the damage. In the field there are two indicators for damage to the seed: broken seed and scuffed seed. The combine operator must insure that there is less than 2% broken seed and that less than 2% of the seeds are scuffed. In countries where sesame is used for oil, there is a free fatty acid test, but in the US where the major market is the confectionary trade, there is no such test at this time. However, loads are segregated based on broken and scuffed seed.

In any crop, a combine operator must be very aware how much seed is going out the back of a combine and lost. He can adjust cylinder speed and concaves to insure the seed is threshed out of the plant, and he can adjust air and screens to make sure the seed is not passed out the back. When operators threshed the id/id ‘S01’, they found many intact capsules. Thus, they closed the concaves and increased cylinder speed to insure that all of the capsules were opened. Even with an open capsule, the impact of the force could crimp the hole and the seed would remain inside. The operators had to choose between 6%–15% broken and little seed going out the back or 1%–2% broken and as much as 20% of the seed going out the back. The farmer was faced with either a loss of yield or quality discounts.

The problems of seed release were greatly ameliorated by going back to the dehiscent capsule architecture because of the opening of the capsule. However, in developing the six factors of seed hold, it was determined that there was a necessary gray area between expressions of the characters:

1. The capsule should be closed enough to hold the seed and yet open enough to release moisture and the seed.
2. The capsule constriction should be tight enough to hold the seed so they would not rattle but loose enough to release the seed.
3. The placenta attachment should be strong enough to hold the seed in bad weather yet weak enough the release the seed to the lightest possible pressures in the combine.
4. Early in the development cycle it was learned that minimal capsule split led to excessive seed retention. ‘S04’ had a very small capsule opening and tight constriction, but very little split, and it retained as much as 10% of the seed after the combine. Subsequent testing of S04 progeny showed a direct correlation between good release and good capsule split.
5. The only way to retain desirable capsule split was to have good adhesion from membrane completeness and membrane attachment.
6. In the false membranes separating the locules, there is an opening at the end near the tip. In the 1997 testing, the opening was measured. In all cases there was enough opening to allow the seeds to exit the capsules. In recent testing, there have been lines with smaller openings. Some of these openings are large enough to allow seed to exit sideways, but the angle of the seeds to the hole can block the seeds from exiting.
In the initial selection process, the emphasis is on shatter resistance and the shaker shatter resistance testing is used as the main screening criteria. During this testing, for lines that have SSR > 80, the capsules are examined to study the shatter resistance mechanisms to ensure that seed release will not be an issue.

Plants of advanced candidates for a cultivar release are put through plot threshers, and the capsules are examined for seed retention. During breeder and foundation seed multiplication, the capsules coming out of the combines are studied to make sure that the seed is being released properly. In many of the recent cultivars, capsules come out of the combine intact and yet have no seed in them. Current cultivars have less than 1% of the seed remaining in the capsules after the combine. In opening some combines, it has been found that 90% of the threshing is done by the time the sesame clears the feeder housing. Thus, the concaves can be wide open and the cylinder speed only fast enough to move the sesame through the machine.

**OTHER MECHANIZATION CONSIDERATIONS**

Between 1940 and 1981, many researchers worked on modifying farm equipment to solve the problems of mechanizing sesame. In introducing farmers to sesame, one of the difficulties faced was that they would have to purchase new equipment or modify existing equipment. In 1982 Sesaco made the decision to breed the sesame to adapt to existing equipment. The present mechanized sesame can be planted and harvested with standard equipment used for other crops such as cotton, sorghum, and wheat. In addition, different cultivars have been developed to adapt to different row spacing between 35 and 100 cm. Farmers do not like to have different row spacing which may require changes in tractor wheels, bedders, planters, cultivators, and combines. By using plates developed for sugar beets, sorghum, and tomatoes, sesame can be planted with row equipment. The drills should be modern with depth control and small seed metering. Generally, rows are plugged off on drills to maintain 35 cm or more spacing.

Other important plant/machine interfaces are as follows: height of the plant, height of the first capsule, branching, lodging resistance, weed control, crop drydown, capsule loss, seed cleaning, planting seed germination, and seedling emergence.

In breeding for improved plant/machine interfaces, many compromises have been necessary. The following paragraphs describe how breeding for one objective can affect other objectives. The primary objective has not been to increase yield in plants, but rather to develop a plant/machine system that will increase yield in the combine bin.

**Height of the Plant.** When swathing sesame or in direct harvest, the plants should be short enough so that the reel pulls in the plants rather than first pushing them out and then pulling them in. Since there is no reel, initially row crop headers were used which could handle plants over 180 cm, but there were still problems with the plants bridging over the augers and not feeding properly into the feeder housing. The maximum height acceptable for all harvest implements is 150 cm and lower plants are preferable.

**Height of the First Capsule.** Whether swathing or direct combining, the cutter bar should be below the lowest capsule. In a laser leveled field the first capsule at 15 cm is adequate, but when using a 9 m header in the hills of Oklahoma, the first capsule should be higher than 30 cm. The capsule zone is defined as the plant height minus the height from the ground to the first capsule. The longer the capsule zone, the higher the yield. However, if the capsule zone is increased by height or by lowering the first capsule, there are harvesting problems that compromise any increase in yield.

**Branching.** In the binder, it is preferable to have uniculm lines, but branches help in swathing and combining. In both auger and belt swathers, branched plants will become intertwined making it easier to move the plants to the windrow. In picking up the windrows, the intertwining also helps in moving the plants into the combine. In looking at harvested fields, it is simple to pick out the uniculm and branched fields: the uniculm fields have more trash piles where the combine had to stop and back-up after plants went below the pick-up attachment and blocked feeding from the windrow. In direct harvest this same intertwining helps the header auger to move the plants to the feeder housing. However, if there is too much branching, it is difficult to separate the crop at the edge of the header. With too much intertwining, separating the crop can cause loss of capsules and/or shattering of seed. Beech and Imrie (2001) also prefer branching, but their rationale is related more to problems with cutting the thick stems of uniculm lines.

**Lodging Resistance.** Every crop must be lodging resistant. There are two directions for breeding for
lodging resistance: strong woody stems or thin wiry stems that will bend in the wind. The major objective is to keep the stems from breaking. If they are too woody, they will break the teeth on the cutter bars, it will be difficult to pick them up with a pick-up attachment, and they will bridge over the auger in a header. Woody stems are more susceptible to lodging and breaking in the first 40 days than wiry stems. Later in the season, wiry stems are more susceptible to lodging but seldom break.

**Weed Control.** One of the major obstacles to mechanizing sesame is the lack of registered herbicides. It is a general chicken/egg problem: major chemical companies do not develop herbicides for minor crops, and a crop cannot become a major crop without an herbicide. The problem has become more important with the advent of “Roundup Ready” cotton. In years past, in most of Texas and Oklahoma there were manual laborers to hoe the fields. These crews are now almost non-existent for use in sesame. An obvious solution would be to develop “Roundup Ready” sesame. However, developing a GM crop when the largest importers in the world are anti-GMO is a risky endeavor, particularly since the Asians use sesame specifically for health. Currently the US IR4 program is in the process of clearing two herbicides for sesame, and more work is in progress. The IR4 program is designed to approve the use of chemicals on minor crops. In the meantime, the emphasis is on planting into clean fields and cultivating.

On the breeding side, the concept is to provide a ground cover as quickly as possible (Martin 1995). From the 1940s the strategy was to use large lower leaves (B. Mazzani, pers. commun.). The larger leaves also had another benefit in that these plants could surge through early insect infestations. Another way of getting quick cover is to space the rows more closely. However, as noted above, a 100 cm row cotton grower does not want to plant 35 cm sesame rows. Another factor in row spacing is cultivation. Although it is possible to set up tractors for narrow rows, these require slow speeds to cultivate and increase the cost of the operation. In addition, the trends in the US are towards larger fields and larger tractors with wide wheels.

A second factor is the acceleration of growth (takeoff) of the plants. Sesame has very small seeds. The initial size of the cotyledons is dependent on the seed size and the depth of planting. The smaller the cotyledons, the longer it takes for the plant to gain momentum and start growing after emergence. Part of the problem is the cotyledon, but the other part of the problem is that sesame concentrates much of its earlier development on pushing down its root. Beech and Imrie (2001) feel this is important for drought resistance. Sesaco has found that it is important also for irrigated crops because the deeper the roots, the less dependent the crop is on timely and frequent irrigations. Even with such importance, takeoff is difficult to breed and select for. Sesaco for many years took a note of “number of days until 60 cm tall.” However, most of the breeding lines hit this point within one week, but more importantly, the same seed planted in different parts of the field could give substantially different growth, depending on the depth of planting. Once sesame hits the 60 cm height, the growth can be very fast until the onset of flowering. One Arizona grower measured 45 cm of growth in 7 days.

In breeding for large leaves and quick takeoff, the resulting plants are often taller with a higher first capsule. Thus, quick ground cover is a difficult objective to accomplish while staying below 150 cm and having a 30 cm first capsule.

**Crop Drydown.** When sesame plants are cut at maturity there are a few drying issues. In shocks, the outer bundles dry earlier than the inner bundles. In windrows, the plants on top of the windrow dry earlier than those near the ground. Shorter plants dry faster than the older taller cultivars. When sesame is harvested direct, the amount of time between physiological maturity and harvest is much longer than desired. Without a frost, this can be as much as 60 days. In Australia, Reglone is used to dry down the crop, but Beech and Imrie (2001) state that under certain conditions this does not work well. In the US the FDA might not approve the use of Reglone on a food crop. Drydown is important in the US because sesame is grown in the summer and harvested in the fall. The longer the crop is in the field, the shorter and cooler the days, and there is often more rain. If there is persistent warm wet weather, mold can form on the plants, capsules, and seed.

In Sesaco a tremendous amount of selection pressure has been applied to enlarge the swathing window which also extends the amount of time until complete drydown. Breeding for larger seed size (discussed below) has also led to longer drydown. Taking drydown notes has also been complicated by root rots. It is difficult to distinguish between plants dying from a root rot and natural drydown. Recently, some lines with
larger seed, root rot tolerance and quick drydown have been identified, and hopefully, quick drydown can be improved through breeding without having to resort to desiccants. Desiccants will require labeling, cause concern in the health food market, and increase the cost of growing sesame.

Capsule Loss. When leaving sesame for direct harvest, after the leaves drop there can be rubbing of stems and branches in the wind. There are some lines, particularly triple capsule lines, where the capsules break off the plant. In constant winds there have been as much as 70% loss. A strong attachment of the capsule to the stem and the angle between the capsule and stem are important. However, capsules that hug the stem do not break off readily (and are less susceptible to hail), but they drydown slowly.

Seed Cleaning. As with any seed, the higher the foreign matter content, the more difficult it is to clean. Sesame has three plant parts that can be difficult to clean: petioles, pedicels, and nectaries. The petiole problem has been solved through defoliation. The pedicels that hold the capsule to the stem should not break off. In single capsule per leaf axil lines, there are two nectaries. These are smaller than seed and weigh less, but in quantity, they are difficult to remove. Beech and Imrie (2001) identified the same problem in Australia. Breeding efforts continue to reduce the size of the nectaries, and hopefully, one day there will be a mutation without nectaries. The nectaries can also be eliminated by selecting lines with multiple capsules per leaf axil.

Planting Seed Germination. M.L. Kinman (pers. commun.) showed a direct correlation between seed damage and germination—the higher the damage the lower the germination. Initially the standards for planting seed were set at 70% germination because it was so difficult to develop planting seed with higher germination rate. Even damaged seed has good germination after combining, but planting is 6–8 months after harvest. In the 1980s the germination rates varied between 65% and 80%, even with rotary combines. The primary problem was that the swathing method of harvest was used. When the plants are on the ground, if there is a hard rain, the sand/dirt will splatter on to the plants. This sand/dirt often will travel with the seed into the combine. As the seed is moved through a series of augers, the sand/dirt acts as an abrasive and damages the seed coat. Presently, with direct harvest methods the germination rates vary between 75% and 95%. One of the critical aspects is harvesting at very low moisture contents. The ambient humidity at harvest is a large factor in getting the lowest moisture contents. Tarping/untarping trucks at the appropriate time can also be a factor.

Seedling Emergence. One of the most difficult problems in planting sesame is that the seeds are small and should be placed precisely in the soil. They cannot be so deep that the cotyledons never reach the surface, and yet they cannot be so shallow that the moisture around the seed is lost. Seed damage can be a factor in reducing the vigor of the seed. At present, there is continual selection pressure to larger seeds that will have more energy to push up the soil and emerge from deeper placement. Modern equipment with depth control is essential for sesame planting. One of the best insurance policies for a good stand is to plant more seeds than necessary. Two adjacent seeds can push through the soil better than a single seed.

CONCLUSIONS

For 60 years there have been efforts to move sesame from a manual crop to a mechanized crop. Considerable progress was made between 1940 and 1965, but there was still a limited amount of manual labor necessary in the harvest. The first completely mechanized cultivars were developed in the early 1980s, and there has been continuing progress. Sesame can become a major oilseed only with lower prices. Lower prices can only be achieved through increased yields and lower production costs. Progress in mechanizing sesame has been slow because of the need to combine many characters using a building block methodology. The most critical objective of developing shatter resistance has been solved by Sesaco. Now that most of the other plant/machine interface problems have been addressed, attention is turning to increasing yield. In addition, breeding continues on characters such as seed quality, disease resistance, insect resistance, hail resistance, and drought resistance.

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Trends in New Crops and New Uses


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