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Kenaf Production: Fiber, Feed, and Seed

Charles L. Webber III, Harbans L. Bhardwaj, and Venita K. Bledsoe

INTRODUCTION

Kenaf (*Hibiscus cannabinus* L., Malvaceae) is a warm season annual fiber crop closely related to cotton (*Gossypium hirsutum* L., Malvaceae) and okra (*Abelmoschus esculentus* L., Malvaceae) that can be successfully produced in a large portion of the United States, particularly in the southern states. As the commercial use of kenaf continues to diversify from its historical role as a cordage crop (rope, twine, and sackcloth) to its various new applications including paper products, building materials, absorbents, and livestock feed, choices within the decision matrix will continue to increase and involve issues ranging from basic agricultural production methods to marketing of kenaf products. These management decisions will require an understanding of the many different facets of kenaf production as a fiber, feed, and seed crop.

HISTORY

Kenaf has been used as a cordage crop to produce twine, rope, and sackcloth for over six millennia (Dempsey 1975). Kenaf was first domesticated and used in northern Africa. India has produced and used kenaf for the last 200 years, while Russia started producing kenaf in 1902 and introduced the crop to China in 1935 (Dempsey 1975). In the United States, kenaf research and production began during World War II to supply cordage material for the war effort (Wilson et al. 1965). The war not only interrupted the foreign fiber supplies from countries such as the Philippines, but the US involvement in the war also increased the use of these fibers by the US. Once it was determined that kenaf was a suitable crop for US production, research was initiated to maximize US kenaf yields. Asa result, scientists successfully developed high-yielding anthracnose-resistant cultivars, cultural practices, and harvesting machinery that increased fiber yields (Nieschlag et al. 1960; Wilson et al. 1965; White et al. 1970). Then in the 1950s and early 1960s, as USDA researchers were evaluating various plant species to fulfill future fiber demands in the US, it was determined that kenaf was an excellent cellulose fiber source for a large range of paper products (newsprint, bond paper, and corrugated liner board). It was also determined that pulping kenaf required less energy and chemical inputs for processing than standard wood sources (Nelson et al. 1962). More recent research and development work in the 1990s has demonstrated the plant's suitability for use in building materials (particle boards of various densities, thicknesses, with fire and insect resistance), adsorbents, textiles, livestock feed, and fibers in new and recycled plastics (injected molded and extruded) (Webber and Bledsoe 1993).

Fig. 1. Kenaf stalks at harvest, 150 days after planting, cultivar 'Everglades 41', at USDA, ARS South Central Agricultural Research Laboratory, Lane, Oklahoma.

BOTANY

Plant Components

Stalks. The length of the growing season, the average day and night temperatures, and adequate soil moisture are considered the key elements affecting kenaf yields (Fig. 1). Stalk yields normally range from 11 to 18 tonnes (t)/ha, oven dry weight, depending on the previously listed production factors. In addition to its low economic inputs and high stalk yields, suitable production areas for kenaf will depend greatly on the economics of the competing crops and the kenaf market.

The kenaf cultivar 'Tainung #2' (photosensitive) has consistently surpassed other cultivars in yield evaluations in the United States. For the purpose of comparison, kenaf stalk yields (stalks without leaves) are reported at

0% moisture within this manuscript, as is standard in most published kenaf research. In yield component research conducted by the USDA, ARS, at their field station in Lane, Oklahoma, 'Tainung #2' produced the greatest yields in a 2-yr study with five kenaf cultivars (Webber 1993b), and in a 3-yr study with sixteen kenaf cultivars (Webber 1997). 'Tainung #2' stalk yields averaged 13.8 t/ha in the 2-yr study and 21.8 mt/ha in the 3-yr study. The USDA has also developed a kenaf cultivar, 'SF-459', that produces superior stalk yields compared to other cultivars if the soils are infested with certain detrimental nematodes (Cook et al. 1995).

Leaves. Kenaf plants produce simple leaves with serrated edges on the main stalk (stem) and along the branches. The position of these leaves alternate from side to side on the stalk and branches. Cultivar and plant age affect the leaf shape. Kenaf plants produce two general leaf types, divided and entire (Fig. 2). The divided (split-leaf) cultivars have deeply lobed leaves with 3, 5, or 7 lobes per leaf. 'Everglades 71', 'Tainung #1', 'Tainung #2', 'Guatemala 51', and 'SF-459' are examples of divided leaf cultivars. The entire leaf cultivars ('Everglades 41', 'Guatemala 4', 'Guatemala 45', 'Guatemala 48', 'Cubano', 'Cuba 108', 'Cuba 2032', and 'N7') produce leaves that are shallowly lobed, that are basically cordate (heart-shaped). Jones et al. (1955) reported that the divided leaf characteristic was dominant and the entire leaf shape was recessive.

The juvenile or young leaves on all kenaf seedlings are simple, entire, and cordate. As the kenaf plant matures and additional leaves are produced, the newer leaves start to differentiate into the leaf shape characteristic of that particular cultivar. Divided leaf cultivars can produce 3 to 10 entire juvenile leaves prior to producing the first divided leaf.

Each leaf also contains a nectar gland on the mid-vein on the underside of the leaf (Dempsey 1975). The leaf and seed capsule nectar glands are visited in large numbers by wasps (*Campsomeris trifasciata* Fabr.) (Jones et al. 1955). Although these wasps may be present in large number during flowering, they seem to restrict their activity to the leaf and capsule nectar glands, rather than the flowers.

Flowers and Pollination. Kenaf plants produce large showy, light yellow, creamy colored flowers that are bell-shaped and widely open (Fig. 3). The flowers of many cultivars have a deep red or maroon colored center. The flowers are 8 to 13 cm in diameter with 5 petals and are borne singly in the leaf axis along the stalk and branches. The complete flowers are indeterminate; therefore the plant continues to produce additional flowers. Although the plants are highly self-fertile, generally considered self-pollinated, the plants can be cross-pollinated. Jones et al. (1955) reported that the nature of the kenaf pollen prevents wind dispersal and that any cross-pollination is a consequence of insect activity. The flowers open and close in a single day and are either cross-pollinated, primarily by domesticated honey bees (*Apis mellifira* L.) (Tamargo and Jones

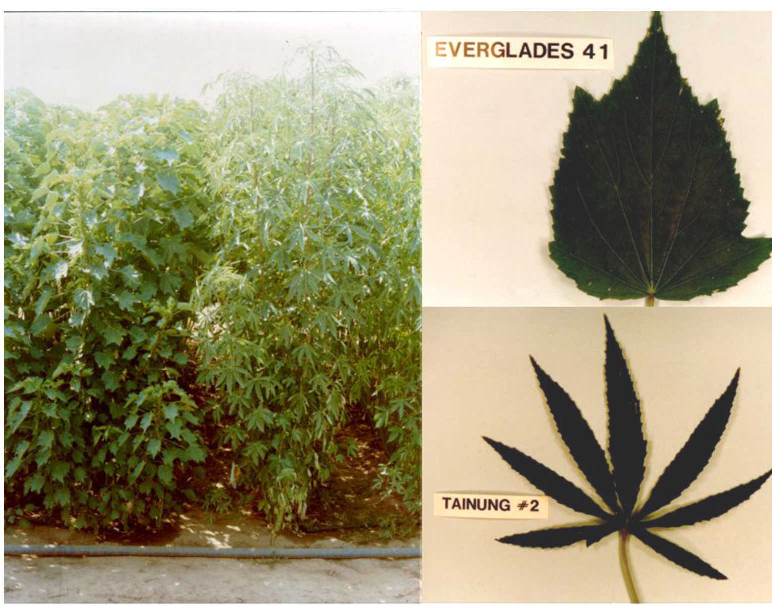

Fig. 2. Leaves and plants of kenaf cultivars 'Everglades 41' (top and left) and 'Tainung #2' (bottom and right).

Fig. 3. Kenaf flower.

1954), or self-pollinated by the twisting closing movement of the petals. Tamargo and Jones (1954) reported the cross-pollination for 9 strains ranged from 2% to 24%. Jones et al. (1955) reported 0.16% crossing for cultivars separated by 25 m and suggested this distance as a minimum between large seed production blocks. Even at 302 m between cultivars there was 0.14% crossing.

Seed and Seed Capsules. Following pollination, a pointed, ovoid, seed capsule is formed that is about 1.9 to 2.5 cm long and 1.3 to 1.9 cm in diameter. The seed capsules are covered with many small, fine, loosely held, hairy structures that are very irritating when in contact with human skin. Each capsule contains 5 segments with a total of 20 to 26 seeds/ capsule (Dempsey 1975). The slate-black, wedge-shaped kenaf seeds are approximately 6 mm long and 4 mm wide, with 35,000 to 40,000 seeds/kg (Fig. 4). Once pollinated, the seeds require 4 to 5 weeks to maturation (Crane and Acuna 1945).

Photosensitivity

Kenaf cultivars differ in their sensitivity and response to day-length, although it is actually the length of darkness that is the critical element that triggers the response. And it is the latitude north and south of the equator that determines the day-length for any particular time of the year. Understanding the influence of day-length (latitude) is fundamental in selecting the optimum cultivar for the production location and the intended use of the crop. Dempsey (1975) divides kenaf cultivars into three maturity categories: ultra-early, early to medium, and late-maturing. In the US, discussion of photosensitivity is generally restricted to early to medium and late maturing cultivars, which are referred to as photosensitive and photoinsensitive, respectively.

Ultra-Early Maturing. The ultra-early maturing cultivars were developed for use at latitudes greater than 37° north (Dempsey 1975). These include the Russia and Korea cultivars that mature in 70–100 days. Even though these cultivars have high seed yields, the compressed growing season produces shorter plants with lower fiber yields. These cultivars are not grown at lower latitudes (e.g. United States) because they will flower even earlier, and therefore produce even shorter and lower yielding plants (Dempsey 1975).

Early to Medium Maturing. The cultivars in the remaining two maturity categories, early to medium and late maturing, are normally simply referred to as photosensitive and photoinsensitive respectively. Photosensitive (early and medium maturing) cultivars, classified as short-day plants, are typically preferred for fiber production in the United States. Two of these, ‘Everglades 41’ and ‘Everglades 71’, were developed by USDA researchers for the US to increase disease resistance and extend the vegetative growing period before the plants initiate flowering (Wilson et al. 1965). These photosensitive cultivars initiate flowering when the day length decreases to approximately 12.5 hours, which is mid-September in the southern states (Scott 1982). It is advantageous to delay flowering in these cultivars, because the initiation of flowering causes a reduction in vegetative growth rate (Dryer 1967). As a result of late floral initiation and inability to produce mature seed prior to a killing frost, seed production in the US for these cultivars is limited to southern Florida, the Lower Rio Grande Valley of Texas, and southern-most areas of Arizona and California (Scott 1982). If these cultivars, ideally suited for production between latitudes of 10° to 27° N or S, are grown in equatorial latitudes (0° to 10° N or S) they will flower very early (60 to 80 days) and produce much lower yields than at the more northern latitudes (e.g. southern US).

Late Maturing. Photoinsensitive, late maturing, (also referred to as day-neutral) cultivars are ideally suited for the latitudes surrounding the equator, 0° to 10° N or S. Although usually referred to as photoinsensitive, these cultivars may still be responsive (semisensitive) to day length for flowering initiation (Dempsey 1975). If these cultivars (e.g. ‘Guatemala 4’, ‘Guatemala 45’, and ‘Cuba 2032’) are grown within the US, they initiate flowering as early as 100 days after planting, rather than waiting until the day length decreases to 12.5 hr (Dryer 1967; Dempsey 1975). Therefore, these cultivars can be

Fig. 4. Kenaf seed.

planted in May or early June in the United States (30° to 40°) and still have ample time to produce mature seed. Unfortunately, earlier floral initiation and the resulting seed production decreases the rate of vegetative growth resulting in lower stalk and fiber yields compared to the photosensitive cultivars (e.g. 'Everglades 41' or 'Everglades 71') (Dempsey 1975).

Photosensitivity and Kenaf as a Forage Crop. Photoinsensitive kenaf cultivars may be ideally suited for use as forage or livestock feed crops within the US. As a livestock feed, kenaf is usually harvested at an earlier growth stage than as a fiber crop; 60 to 90 DAP compared with 120 to 150 DAP (Webber 1993a). During a shorter growing season, photoinsensitive cultivars (e.g. 'Guatemala 4', 'Guatemala 45') can produce dry matter yields equivalent to or greater than photosensitive cultivars, while using seed that can be produced in a larger geographic area (Webber 1993a).

FIBER PRODUCTION

Planting

In the United States, kenaf can be planted in the spring once the soil has warmed to 13°C and the threat of frost is past. In most areas, kenaf can be planted as early as April or May. Planting can be accomplished by using standard planting equipment in a wide range of row spacings, and can be planted on raised beds or on flat ground. The slate-black, wedge-shaped kenaf seeds are approximately 6 mm long and 4 mm wide, with 35,000 to 40,000 seeds/kg. Kenaf and grain sorghum (*Sorghum bicolor* L.) seed are similar in size, and therefore kenaf has often been planted using grain sorghum planting plates in commercial planters. Kenaf seed is planted 1.25 to 2.5 cm deep, and normally emerges within two to four days after planting. Because the kenaf seed color often makes it difficult to see the seed when testing the planting depth and placement, it is often helpful to test planting depth with seeds that are more easily detected.

Plant Populations

Final plant populations of 185,000 to 370,000 plants/ha (75,000 to 150,000 plants/acre) are desirable for maximum yields and the production of single stalk plants with very little or no branching. To achieve the middle range of plant populations will require about 8 kg/ha of seed (corrected to 100% germination). Research has shown that when plant populations drop below the 185,000 plants/ha the stalk yields usually also decrease (Higgins and White 1969). At low plant populations the crop produces plants with multiple branches, rather than the more desirable single stalk plants that are easier to mechanically harvest. If kenaf is planted at the upper plant populations of 370,000 plants/ha the crop compensates through competition to the available environmental resources (light, soil moisture, and nutrients) by reducing the total number of plants to a more sustainable population. Although basal stalk diameters may vary greatly within a given kenaf field, at satisfactory populations the average basal stalk diameters will be in the range of 1.9 to 3.8 cm. Plants along the field's outward border are usually larger and branched in the direction away from the kenaf field.

Fertility

One of kenaf's advantages as a crop, is it can be successfully grown in a wide range of soil types, from high organic peat soils to sandy desert soils (Dempsey 1975). Although kenaf grows better on well-drained, fertile soils with a neutral pH, the crop can withstand late season flooding, low soil fertility, and a wide range of soil pH values (Dempsey 1975). Kenaf also has shown excellent tolerance to drought conditions.

Proper fertility maintenance, especially supplemental nitrogen application, is needed to optimize kenaf yields, and minimize production costs. As the result of the inherent differences between soil types with respect to soil fertility, soil texture, organic matter, and pH, there is a wide range of reported responses to fertilizer applications on kenaf crop production. White and Higgins (1965) reported inconsistent differences relative to the effects of N on kenaf stalk yields. Researchers in Georgia have reported both positive (Adamson et al. 1979) and no benefits (Massey 1974) to N applications. Studies in Florida demonstrated that the positive response to N applications on stalk yields were dependent on soil type (Joyner et al. 1965), where kenaf grown on a sandy soil responded to N and did not respond to N on a peat soil. Bhangoo et al. (1986) in California, and Sij and Turner (1988) in Texas, increased stalk yields with the addition of N to soils with low available nitrogen. Stalk yields in Missouri (Ching and Webber 1993) on a silty clay soil and in Nebraska (Williams 1966) on a silty clay loam soil did not benefit from N applications. Stalk yields have also responded differently to N at the same location and soil between years (Hovermale 1993). When researchers in Florida (Pate et al. 1954) compared differences in kenaf stalk production and fiber content between a highly organic Everglades peat soil and a low organic Immokalee sandy soil, they discovered that with proper fertilization both crops grew to the same height and produced the same fiber yields, but the peat-grown kenaf produced 32% greater green weight, lower fiber percentage, and lower fiber tensile strength, shear, wear, and flex ratings. In a two-year fertility study in Oklahoma (Webber 1996b) using five nitrogen application rates (0, 56, 112, 168, and 224 kg N/ha) on a Bernow fine sandy loam, 0%–3% slope, (fine-loamy, siliceous, thermic Glossic Paleudalf) it was determined that stalk yield tended to increase as N applications rates increased up to 168 kg N/ha, and at 224 kg N/ha a reduction in stalk yield occurred compared to the 168 kg N/ha level. In the Oklahoma study excess N application was detrimental to stalk yield (Webber 1996b).

Weed Control

Though kenaf grows quickly and competes well with weeds, initial weed control is often required. Researchers have reported that kenaf is a good competitor with weeds once the plants are of sufficient size to shade the ground (Orsenigo 1964; Burnside and Williams 1968), yet weeds can significantly reduce kenaf yields. Weed control, therefore, becomes an important consideration in obtaining optimum kenaf yields.

Williams (1966) reported that weed competition, with moderate weed pressure, reduced stalk yields during one season by an average of 1.0 t/ha. Weed competition in a three year Nebraska study significantly reduced yields by an average of 69%, while reducing plant height and stalk diameter (Burnside and Williams 1968). Many herbicides originally evaluated for use in kenaf production are either no longer available, phytotoxic to kenaf, or reduce kenaf populations (Orsenigo 1964; Williams 1966; Burnside and Williams 1968). There are a number of efficacious preemergence herbicides that have registration potential for kenaf, including metolachlor, trifluralin, and pendimethalin.

Trifluralin has been the standard herbicide used by kenaf researchers (White et al. 1970) and has recently been registered for use in kenaf grown for fiber. Burnside and Williams (1968) tested seven herbicides and found that kenaf was most tolerant to trifluralin; trifluralin also provided excellent weed control. However, trifluralin at 2.2 kg ai/ha (ai = active ingredients) reduced kenaf yields by 3.9 t/ha, 25%, during the first year, even though stalk heights and diameters were unaffected. Orsenigo (1964) reported a 50% phytotoxicity and a 50% stand reduction when trifluralin was applied to kenaf at 6.7 kg ai/ha, but 100% tolerance and no stand reductions when applied at 2.2, 3.4, and 4.5 kg ai/ha. In south Texas (Hickman and Scott 1989), trifluralin, at 0.9 and 1.7 kg ai/ha, and metolachlor at 3.4 kg ai/ha provided excellent (90%) grass control, while acceptable (80%) total weed control was obtained with metolachlor at 3.4 kg ai/ha. Trifluralin did reduce stalk yields at the rates tested. In Mississippi, metolachlor at 3.0 kg ai/ha caused no visual injury to the kenaf, although stalk yields may have been reduced (Kurtz and Neill 1990). Webber (1992), southeast Oklahoma, reported that preemergence herbicide applications of trifluralin and metolachlor at 0.56, 1.12, and 2.24 kg ai/ha did not visually injure kenaf plants or reduce stalk yields.

More recently researchers (Kurtz and Neill 1992; Webber 1994) have examined the use of a large range of postemergence herbicides on kenaf. In addition, Kurtz (1994) has examined the tolerance of kenaf to postemergence-directed herbicides. In each of these studies a number of herbicides were identified that were both effective in controlling weeds and did not adversely affect kenaf stalk yields. Published herbicide research has provided a solid foundation for weed control systems for kenaf production. Continued research is needed to examine the use of new herbicide chemistry, different application methods, the use of nonchemical methods of weed control, weed competition, and the fate of herbicides applied in conjunction with kenaf production. Research will also be required for the registration of specific herbicides.

If kenaf plant material has the potential of entering the human food system through livestock feed or animal litters, it's important to know whether the herbicides used are present in kenaf plant material. Webber (1996a) investigated the effect of herbicide applications of trifluralin and pendimethalin at rates of 0.56, 1.12, and 2.24 kg ai/ha on the presence of herbicide residues in kenaf plant material (leaves and stalks). There were no visual phytotoxicity symptoms observed for either herbicide. Chemical and data analyses determined that trifluralin and pendimethalin were not present in kenaf at detectable levels for any of the application rates for either harvest date (75 and 150 DAP). Weeds in the weedy-check treatment reduced kenaf stalk yields at 75 DAP by an average 1.8 t/ha compared to the weed-free treatment. Additional research should focus on the influence that weed species, weed density, and time interval have on limiting full-season yields of kenaf and also how these factors interact with limited soil moisture. Trifluralin and pendimethalin are promising herbicides for use in kenaf production. Expanding the registration label to include these herbicides for use in kenaf production for livestock feed would be beneficial in establishing kenaf as a commercial crop. Always read and follow the herbicide labels for application methods, herbicide rates, and crop clearances.

Crop Rotation

As kenaf production in the United States continues to increase, it is essential to integrate this alternative fiber and feed crop into existing cropping systems. Including kenaf in a crop rotation with a legume crop is an excellent management strategy that has the potential to provide numerous crop production advantages, including reduced pest problems and increased soil fertility. Soybean [*Glycine max* (L.) Merr., Fabaceae] is a legume crop that is also grown throughout the same production areas where kenaf can be successfully produced. Research with kenaf-soybean crop rotations indicated that the crops were indeed compatible (Webber 1999). The research determined that stunt (*Tylenchorhynchus* spp.) nematode populations decreased as a result of kenaf production. The significant reduction in stunt nematodes benefited the next year's soybean crop.

PRODUCTION FOR LIVESTOCK FEED

Although kenaf is usually considered a fiber crop, the entire kenaf plant, stalk (core and bark), and leaves, can be used as a livestock feed. Research indicates that it has high protein content (Clark and Wolff 1969; Killinger 1969). Crude protein in kenaf leaves ranged from 14% to 34% (Killinger 1969; Suriyajantratong et al. 1973; Swingle et al. 1978; Webber 1993a), stalk crude protein ranged from 2% to 12% (Swingle et al. 1978; Webber 1993a), and whole-plant crude protein ranged from 6% to 23% (Killinger 1969; Swingle et al. 1978; Webber 1993a). Kenaf can be ensilaged effectively, and it has satisfactory digestibility with a high percentage of digestible protein (Wing 1967). Digestibility of dry matter and crude proteins in kenaf feeds ranged from 53% to 58% and 59% to 71%, respectively (Wing 1967; Suriyajantratong et al. 1973; Swingle et al. 1978). Kenaf meal, used as a supplement in a rice ration for sheep, compared favorably with a ration containing alfalfa meal (Suriyajantratong et al. 1973). It has also been determined that chopped kenaf (29% dry matter, 15.5% crude protein, and 25% acid detergent fiber) is a suitable feed source for Spanish (meat-type) goats (Wildeus et al. 1995).

The majority of the breeding programs in the US have developed cultivars that are more suitable for fiber production (stalk yield, self-defoliating, greater stalk percentages, reduced branching) than for forage production. The leaf yields and leaf biomass percentages are important considerations in selecting cultivars to be used for kenaf forage production, because the leaves are the primary source of protein (Webber 1993a). Scientists have reported differences among cultivars for leaf biomass percentages (Webber 1993a, b) and whole plant protein yields (Webber 1993a; Bhardwaj and Webber 1994). Webber (1993b) reported that cultivar 'Guatemala 51' had the greatest leaf biomass percentage (32% leaves) among 5 cultivars (1993a) and 'Guatemala 45' had the greatest leaf biomass percentages (30.9% leaves) among 6 cultivars.

Researchers evaluating kenaf as a potential forage crop also determined that the age of plant at harvest can influence plant composition, such as leaf percentages, and protein content (Webber 1993a; Bhardwaj and Webber 1994). The leaf biomass percentage and percent crude protein decreased as the kenaf plant increased in height and maturity. This composition and quality change occurred because the lower leaves senesce, often producing plants at DAP without leaves on the lower one-half to three-quarters of the plant stalk. Webber (1993a) reported leaf biomass percentages decreased from 36.2% at 76 DAP to 20.2% for a full season kenaf. Bhardwaj and Webber (1994) determined in a forage evaluation of 6 cultivars that kenaf plant crude protein decreased from 5% to 8% between harvests at 70 to 140 DAP. Bhardwaj et al. (1995) examined the prospect of multiple kenaf forage harvests during a single growing season, harvesting kenaf at 85, 92, and 99 DAP and then reharvesting the same plants at 179 DAP. The research demonstrated the feasibility of multiple kenaf harvests, and that kenaf protein during the second harvests was equal to or greater than the first harvests.

SEED PRODUCTION

Seed production strategies are affected by the cultivar, location—especially latitude, and cultural practices. The first issue to address is the cultivar photosensitivity, whether the cultivar is an ultra-early, an early to medium, or a late maturing cultivar. The best yielding fiber cultivars for the US belong to the early to medium maturing group, which include ‘Everglades 41’, ‘Everglades 71’, ‘Tainung #1’, ‘Tainung #2’, ‘SF-459’, ‘N7’, ‘Cuba 108’, and ‘Cubano’. As discussed above, these cultivars initiate flowering in the southern US during mid-September and will not produce sufficient viable seed prior to a killing frost at most US locations. Therefore, seed production in the United States for these cultivars is limited to areas with very limited potential for freezing temperatures, such as southern Florida, the Lower Rio Grande Valley of Texas, and southern-most areas of Arizona and California (Scott 1982). Obviously seed for these cultivars can also be reproduced south of the US in Mexico and Central America.

Seed Yields

Researchers and producers have reported successful efforts to produce large seed yields in southern Florida, 3,819 kg/ha (Seale et al. 1952; Joyner and Wilson 1967), southern Texas, over 1,013 kg/ha (Scott 1982; Cook and Scott 1995; Scott and Cook 1995), and Mexico, 997 kg/ha (Mullens 1998). Each of these locations has also reported the need to trade off seed yields for harvest efficiency. The advantage of harvesting maximum seed yields from tall kenaf plants must be balanced with the disadvantage of decreased mechanical harvesting efficiency resulting from running large volumes of very tough, rope-like plant material through a combine. Rather than producing the highest seed yields from plants that might be 6 m tall and/or greatly branched, it is more desirable to harvest single stalk plants of limited height, 1.8 to 2.4 m tall, and harvest less seed. This trend will likely continue until new and more efficient harvesting machinery is developed. Hand harvesting the seed is not a very realistic alternative, not only would hand harvesting be very labor intensive, but it would be very disagreeable work because of the presence of the many, small, loosely held, very irritating spines on the seed capsules.

Planting Date for Seed Production

Researchers and seed producers have reported that the strategy for maximizing harvestable kenaf seed is very different than the production approach in maximizing kenaf fiber yields (Seale et al. 1952; Joyner and Wilson 1967; Scott 1982; Cook and Scott 1995; Scott and Cook 1995; Mullens 1998). Cultural methods, such as planting date, fertilization, and plant populations, are altered to maximize seed yields while limiting the vegetative growth of the plant, especially plant height and excess branching. Seale et al. (1952) studied the effect of planting date (April through August) on seed yields in Florida. They reported that although July plantings produced the greatest seed yields, the plants are usually too tall to harvest effectively by machines. These results were consistent with other researchers in Florida (Joyner and Wilson 1967), Texas (Scott 1982; Scott and Cook 1995), and Mexico (Mullens 1998). The consensus among these different reports is that the suggested time to plant photosensitive, early to medium maturing cultivars, is between August 1 and early September. Planting earlier than August 1 usually results in plants with excess height and dry matter for efficient mechanical harvest, and planting after early September results in insufficient vegetative growth to produce sufficient seed yields.

Researchers have also made many practical recommendations concerning planting for seed production within the August to September time frame. Scott (1982) and Scott and Cook (1995) in south Texas (Lower Rio Grande Valley) have suggested that even if Aug. 15 (Scott 1982) or Aug. 20 (Scott and Cook 1995) is the ideal time to plant kenaf to maximize seed yields, without producing excess plant height at harvest, that for practical reasons planting should be initiated at the beginning of August to prevent planting delays from their mid-August rains. Mullens (1998) recommends planting kenaf in mid to late August or even early September in Tampico, Mexico to produce shorter and more easily harvested plants. Mullens (1998) stresses the importance of having shorter plants, therefore reducing the volume of dry matter passing through the combine. Mullens (1998) states this is a more important consideration than the possible seed loss due to a later planting date.

Seed Production Outside the US and Mexico

Crane and Acuna (1945) reported on the effects of planting date (July 10, Aug. 21, and Aug. 24) and plant spacing on seed yields of photosensitive cultivars in Cuba (latitude 23° N) and summarize seed production for a few other locations outside the US (Brazil, Cuba, El Salvador, and Java). Crane and Acuna (1945) also stressed the importance of the photosensitivity of the cultivars, the production location (especially the latitude), the planting date, and the row spacing. Crane and Acuna (1945) recommended July and August as planting dates for seed production, reporting more seed capsules/plant and greater seed number/plant for the July 10 planting date than either August planting date but the Aug. 21 planting date actually produced more seed/unit area in comparison to the same row spacings during the July 10 planting. The yield advantage for the August planting date was, more likely, a reflection of the importance of plant population, than on the effect of planting date. Although the plant populations of the two planting dates were suppose to be the same, the Aug. 21 planting date had greater plant populations compared to the same row spacing in the July 10 plant date. As plant populations between the two planting dates increased from 36,904 plants/ha (July 10, 301 kg/ha) to 199,289 kg/ha (Aug. 21, 672 kg/ha) so did seed yields/unit area. The importance of plant population is further illustrated by noticing that the Aug. 24 planting date, which had only one plant population (542,510 plants/ha), produced the largest seed yields, 1,719 kg/ha, of any planting date or row spacing.

Crane and Acuna (1945) also reported greater branching, increased seed capsules, and seed yields/plant as the distance between plants increased (decreased plant populations), and reported that although individual plant yields increased, this advantage was offset when compared to the plants with lower seed yields but greater plant populations. In addition, these researchers stressed the detrimental effect of long periods of rainfall and/or high relative humidity during the final period of seed development. Not only do kenaf seeds need to dry out during this period, but there is a danger that the mature seed may actually germinate within the seed capsule while still attached to the plant. There is a connection between plant height and floral initiation data. Plant height (average across row spacings) of the first seed capsule from the ground for the July 10 planting was 1.5 m compared to 1.1 m for the Aug. 21 planting date. This information is important because of the need to increase the mechanical harvesting efficiency by decreasing the volume of dry matter passing through the seed combine, and the advantage of having more seed located closer to the ground. It would seem clear from Crane and Acuna's (1945) research that it would be more advantageous to plant kenaf for seed in August rather than July, and plant higher plant populations, 197,680 plants/ha or greater.

Seed Production and Soil Fertility

Soil fertility is also an important aspect of kenaf seed production. Contrary to what might be expected, seed production on less fertile soils or the use of less fertilizer is preferred for seed production (Seale et al. 1952; Mullens 1998). Research in Florida (Seale et al. 1952) reported decreased seed yields on fertile peat soils compared to moderately fertile sandy soils. Mullens (1998) in Mexico also reports that seed production on rich soils or high fertilizer applications complicate seed harvest by increasing plant vegetation and plant height. As a result, Mullens (1998) suggests only moderate fertilizer applications on marginal soils. In the same way, Rio Farms, Inc., a seed producer in south Texas, applies only 22.5 kg/ha of N and 78.8 kg/ha of P_2O_5 pre-plant to a sandy clay loam soil, with another 90 kg/ha N added later as a side dress (Scott and Cook 1995).

Row Spacing and Plant Populations for Seed Production

As discussed earlier, in the section on seed production outside of the US and Mexico, Crane and Acuna (1945) reported that row spacings (plant populations) in Cuba had a significant effect on seed yield. Their data demonstrated the advantage of greater plant populations, whether comparing seed yields within planting dates or across planting dates. The greatest seed yields were produced with an Aug. 24 planting date with a 52-cm row spacing with 3.8 cm between plants within the row, resulting in a final plant stand of 542,510 plants/ha and 1,719 kg/ha of seed. These results are consistent with research in Florida (Joyner and Wilson 1967) where a July 30 planting of kenaf cultivar 'Everglades 71' produced the greatest seed yields with the greatest plant populations (472,312 plants/ha), utilizing a 17.8-cm row spacing with 12.7 cm between plants within the row. The lowest seed yields, 471 kg/ha, were produced with the lowest plant populations, 36,917 plants/ha, 71-cm row spacings and 38 cm between plants within the row. The research in Cuba (Crane and Acuna 1945) and Florida (Joyner and Wilson 1967) both reported an inverse relationship between the number of seed capsules/plant and seed yield/acre. As the row spacing increased the seed capsules per plant increased and the seed yield/acre decreased.

Rio Farms, Inc. in south Texas grew kenaf seed during the 1940s and has continued to do so for the last 20 years (Scott and Cook 1995) and D.B.M. Farms, Inc. in Tampico, Mexico has produced kenaf seed for the last 10 years (Mullens 1998). Each of these producers considers plant populations an important consideration for maximizing harvestable seed yields. Scott (1982) and Scott and Cook (1995) reported that Rio Farms, Inc. uses either single 76-cm row spacings or double rows on 102-cm beds (2 rows 25.4 cm apart on 102-cm beds), with a target plant population 197,680 plants/ha to 296,520 plants/ha, irrespective of the row spacing. They reported conditioned seed yields from 338 kg/ha to over 1,013 kg/ha, averaging just slightly less than 675 kg/ha. Mullens (1998) reports that D.B.M. Farms, Inc. has moved from 102-cm row spacings to 51-cm row spacings. They have also increase the plant populations in 51-cm rows by decreasing the distance between plants for from 5.1 to 7.6 cm (387,453 to 258,220 plants/ha) down to 3.8 cm to 5.1 cm (516,439 to 387,453 plants/ha). Mullens (1998) reports that D.B.M. farms, Inc. averaged 654 kg/ha, 420 kg/ha, and 493 kg/ha of cleaned seed during the 1994–1995, 1995–1996, and 1996–1997 growing seasons, respectively. During these growing seasons in Tampico, Mexico a 51 ha field planted with ‘Everglades 41’ produced the lowest clean seed yields, 419 kg/ha, and a 22 ha field of ‘Everglades 41’ produced the greatest clean seed yield of 771 kg/ha.

Cook and Scott (1995) conducted research in South Texas to determine the effect of plant populations on seed yields. ‘Everglades 41’ was planted in 102-cm row spacing on Aug. 24 and thinned 13 days later to 4 plant populations (161,851, 227,332, 291,578, and 355,824 plants/ha). The average distance between plants within the 40-in rows after thinning was 6.1-, 4.3-, 3.3-, and 2.8-cm, respectively. When the seed was harvested on Dec. 21, the plant populations had decreased to 101,435, 150,126, 166,348, and 196,778 plants/ha, a decrease of 37.3, 34.0, 43.0, and 44.7%. Although the average seed yield for the study was 560 kg/ha, there were no difference in seed yields among the 4 plant populations, even though the number of seed capsules/plant was the greatest in the lowest population. Cook and Scott (1995) noted the research of Crane and Acuna (1945) and Joyner and Wilson (1967) and suggested that plant populations might have a significant effect on seed yields if the row spacing was decreased to less than 40 in. The large declines in plant populations through the growing season for Cook and Scott (1995), the established production practices of Rio Farms Inc. (Scott and Cook 1995) and D.B.M. Farms, Inc. (Mullens 1998), and earlier research would indicate the best method of increasing seed yields by increased plant populations, beyond having plants 3.8 to 5.1 cm between plants, is to decrease the distance between rows.

Seed Harvesting and Timing

Commercial kenaf seed producers for the US market, Rio Farms, Inc. (South Texas) and D.B.M. Farms, Inc. (Tempico, Mexico) rely on mechanized harvests. As reported earlier, hand harvesting kenaf seed is both labor intensive and can also be very unpleasant work as the result of the many loosely held spiny hairs on the seed capsules. It is also suggested that even when using combining equipment care should be taken to avoid contact with these irritating hairs (Scott 1982). Rio Farms, Inc. used an Allis-Chalmers Gleaner N6 combine to harvest kenaf seed when planted in 2 rows on 102-cm beds. More recently, Scott and Cook (1995) reported that in respect to Rio Farms, Inc., the “most desirable seed harvester is a John Deere all crop header on a rotary combine.” They also mentioned that “conventional sickle bar headers and combines can, and have been used to harvest kenaf seed.” Mullens (1998) reported that typically in Tempico, Mexico the seed capsules are located on the upper two-thirds of the plants at harvest and that D.B.M. Farms, Inc. normally sets their combine cutter bar as high as possible to minimize the number of kenaf stalks falling forward and away from the combine header, even though they may miss the lowest seed capsules (Mullens 1998).

Harvesting kenaf seed of photosensitive cultivars planted in July, August, or September in the southern US or Mexico usually takes place in December or January, 4 to 6 months after planting (Wilson 1965; Dempsey 1975; Scott 1982; Cook and Scott 1995). Although the July plantings might produce the greatest seed yield on the plants, the strategy is to enhance mechanical harvesting by trading lower seed yields for shorter plants.

Wilson et al. (1965) mentions the preference 1.2 to 1.8 m tall plants, while Mullens (1998) reports a target height of 1.8 m to 2.4 m at harvest. Individual seed capsules are ready for harvest when the seed rattles slightly within the capsule and the capsules have turned brown (Wilson et al. 1965). Yet, as a result of the indeterminate flowering process, and the 4 to 5 weeks to produce mature seed (Crane and Acuna 1945), the plant normally has a range of seed and capsule maturity on a single plant. The first flowers produce the lowest seed capsules on a plant and are therefore the most mature capsules. Wilson et al. (1965) suggests seed harvesting should start prior to the time the lowest (most mature) seed capsules begin to dehisce (break open). Rio Farms, Inc. (Scott and Cook 1995) has determined that the best time to harvest is when about 10% of the seed capsules have dehisced.

Seed Cleaning and Conditioning

It is very important to properly clean and condition the seed after harvest to maintain high seed viability (Wilson et al. 1965; Dempsey 1975; Scott and Cook 1995). This is especially important because the seed normally contains at least 20% oil (Mohamed et al. 1995). It may be necessary to immediately clean the seed to remove any green plant material to prevent the seed from heating up (Scott and Cook 1995). This is particularly true if the seed crop was harvested prior to a killing frost that normally helps desiccate the plants. A number of authors stress the importance of drying the seed after harvest (Wilson et al. 1965; Dempsey 1975). Although the maximum seed moisture content for bagging seed going into controlled temperature and humidity storage is 16.5%, it's recommended that the seed moisture content be 14% or less (Scott and Cook 1995). Rio farms, Inc. has successfully used a Crippen model M-4272 seed cleaner with a top screen with 5.56 mm round holes, a middle screen with 3.18 × 19.05 mm oblong holes, and a bottom screen with 3.18 round holes for most of their kenaf seed (Scott and Cook 1995).

SEED STORAGE

Independent of the kenaf cultivar selected, seed storage prior to planting is an important consideration. Kenaf seed has a high oil content, 21.4% to 26.4%, averaging 23.7% (Mohamed et al. 1995), and therefore precautions should be taken to preserve the seed viability, especially when contemplating long-term seed storage. As with other crop seeds containing high oil percentages, seed viability decreases over time when stored at higher relative humidity (RH) and higher temperatures. Research on kenaf seed storage indicated that seed stored at 8% RH remained fully viable for 5.5 years when stored at either –10°, 0°, or 10°C, and fully viable for 5.5 years when stored at –10° or 0°C at 12% RH (Toole et al. 1960).

Seed Treatment

Chemical seed treatment is a common agriculture practice to protect crop seed viability and prevent stand reductions from pathogens. Although no chemical seed treatment is presently registered for use on kenaf seed, research has demonstrated the safety and benefits for kenaf seed (Perez and Summers 1963; Presley et al. 1964; Whiteley 1967; White et al. 1971; Cook et al. 1992). Research was conducted in Texas and Oklahoma to evaluate the effectiveness of 3 fungicides (metalaxyl, carboxin, and captan), applied individually and in combination as seed treatments (Cook et al. 1992). It was determined that seed treatments enhanced stand establishment, did not adversely effect germination, and several treatments reduced mold growth on the seed coat. In addition to protecting seeds and seedlings from seed and soil-borne pathogens, the fungicides also had potential for preserving seed quality. It must be remembered that at the time of this publication the above fungicides were not registered for use on kenaf, and mentioning their use is not meant as a recommendation. In the normal process of cultural and genetic improvement for kenaf, chemical seed treatments have been evaluated for protection from various seed and soil-borne pathogens, for example anthracnose (Presley et al. 1964). The use of resistant or tolerant cultivars is usually the ideal method to control many pathogens. Often chemical seed treatments become a stopgap response until resistant or tolerant cultivars can be developed. Just as chemical seed treatments were developed to control anthracnose in kenaf, the preferred method was the use of resistant cultivars 'Cuba 108', 'Cuba 2032', 'Guatemala 4' ('G-4'), 'Everglades 41', and 'Everglades 71' once they were available.

SUMMARY

The expansion of the commercial industry for kenaf will encompass an understanding of the diverse management systems including the production, harvesting, processing, and marketing kenaf as a fiber, feed, or seed crop, combined with directed research, focused development, and communication among diverse constituencies working closely for economic development. The initial step in managing this system is a greater understanding of the variables within each segment of the kenaf industry. The commercial success of kenaf has important potential economic and environmental benefits in the areas of soil remediation, toxic waste cleanup, removal of oil spills on water, reduced chemical and energy use for paper production, greater recycled paper quality, reduced soil erosion due to wind and water, replacement or reduced use of fiberglass in industrial products, and the increased use of recycled plastics. The activities of private industry augmented by public supported agricultural research continue to provide a diverse range of new kenaf products that suggests a bright future for the continued expansion of kenaf as a commercial crop.

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