

Kenaf Yield Components and Plant Composition

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HISTORY

For over 6000 years kenaf (*Hibiscus cannabinus* L., Malvaceae) was primarily used as a cordage crop and secondarily as a livestock feed (Dempsey 1975). In the wet-retting process the long, strong bark fiber strands were separated from the remaining bark material by a natural bacterial wet-retting process. The long, tall stalks were cut at ground level and either tied in bundles with the bark still attached or the bark was stripped off and tied together without the stalks. The bundles were then placed in ponds or slow moving streams to allow for the degradation and removal of the extraneous material around the bark fiber strands. Once the retting process was completed, the fiber strands were allowed to dry, and then made into twine, which could be further processed into rope or sackcloth. The non-fibrous leafy tops and the leaves from the rest of the plant were often harvested prior to or in conjunction with the harvesting of the bark fiber for livestock feed.

The production and retting process for kenaf remained basically unchanged for thousands of years, from the time it was first domesticated in northern Africa, including its introduction to India 200 years ago, to Russia in 1902, and to China in 1935 (Dempsey 1975). During the first half of the 20th century researchers in many countries, including the US Department of Agriculture (USDA) employees during World War II, developed improved kenaf cultivars, harvesting equipment, and retting processes to maximize kenaf bark fiber strands (cordage) yields and to secure sufficient domestic cordage supplies (Wilson et al. 1965; White et al. 1970). Interest in kenaf as a cordage crop continued through World War II, with only slight secondary consideration for alternative uses. The conclusion of World War II and the increased development and use of synthetic polymers for twine, rope, and sacking decreased the interest in kenaf as a cordage crop in the US, although interest abroad continued. Less developed countries continued to use kenaf as a domestic cordage supply, especially for sackcloth for their agricultural industries (Dempsey 1975).

In the mid 1950s and early 1960s the USDA, after evaluating many plant species to fulfill future US fiber demands, 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 chemicals for processing than did standard wood sources (Nieschlag et al. 1960; Nelson et al. 1962; Wilson et al. 1965; White et al. 1970). Recent research and development efforts have further increased the diversity of uses for kenaf by demonstrating its suitability 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). Kenaf use has grown from singular cordage applications to that of a multipurpose crop with various harvestable components with diverse properties. As a result of the diverse uses for kenaf and the different portions of the plant being used, it is important to gain a greater understanding of the yield components and the factors affecting composition of the plant.

FACTORS AFFECTING PRODUCTION AND COMPOSITION

Introduction

The kenaf plant is composed of multiple useful components (e.g. stalks, leaves, and seeds) and within each of these plant components there are various usable portions (e.g. fibers and fiber strands, proteins, oils, and allelopathic chemicals). The yield and composition for these plant components can be affected by many factors including cultivar, planting date, photosensitivity, length of growing season, plant populations, and plant maturity. Therefore, when discussing kenaf yields and plant composition it is necessary to understand the production factors that influence these plant components and their composition.

It is important to consider moisture content of kenaf samples when discussing plant yields. It is normally accepted within the kenaf industry to report plant yields on an oven-dry basis of 0% moisture. This is an

important consideration when comparing kenaf stalk yields among different locations or kenaf stalks and those of typical tree yields.

Stalk and leaf yields are currently referred to in terms of yield per unit area or the percentage of the total above ground plant material. Both of these references are usually made on an oven-dry weight basis. Normally the plant samples in research studies are dried for at least 48 hr at 66°C, or longer if necessary to attain a constant weight. Cutting the stalks into smaller segments (10 to 20 cm), allowing sufficient space between samples, and using forced air ovens enhances the drying process. Drying at temperatures higher than 66°C is not suggested because the higher temperatures will not only remove the plant moisture but also adversely affect and reduce the final dry matter content.

Typically the stalk yields and their percentage of above ground plant matter will increase throughout the growing season, with the rate of growth reduced by drought, decreasing heat units, and flowering. A killing frost or harvesting will terminate stalk growth. Leaf production continues throughout the growing season, and is reduced by the same factors, but unlike stalk yields, leaf yields will often increase only during the first half of the growing season and level off or even decrease in the second half of the season. The leaf production continues, but as a result of leaf abscission, the older, lower leaves will drop off, as the plant grows taller. The loss of the lower, older leaves limits leaf yields, and results in a decreasing leaf percentage on the whole-plant basis. For example, in a two-year Oklahoma study with five kenaf cultivars, kenaf stalk yields continued to increase throughout the growing season, while the leaf yields leveled off during the growing season, resulting in an average of 74% stalks and only 26% leaves by weight at harvest, 161 days after planting (Webber 1993b).

Cultivars

The majority of the breeding programs in the US have developed cultivars that are more suitable for fiber production (higher stalk yields, self-defoliating, greater stalk percentages, reduced branching) than for leaf and forage production. An example of this strategy is the release of 'Everglades 71' and 'Everglades 41' by the USDA in the mid 1960s. Although both cultivars had greater disease resistance than existing ones, only 'Everglades 71' had significantly greater stalk yields, while 'Everglades 41' was released because it produced a greater stalk percentage (lower leaf percentages) than existing cultivars (Wilson et al. 1965). A newer kenaf cultivar, 'Tainung #2' (photosensitive) has consistently surpassed other kenaf cultivars in US yield evaluations. Within this manuscript and most of the recent kenaf research reports, kenaf stalk yields (stalks without leaves) are reported at 0% moisture. In yield component research conducted by the USDA in Oklahoma, 'Tainung #2' produced the greatest stalk yields in a 2-yr study which included five other cultivars (Webber 1993b), and in a 3-yr study including 16 cultivars (Webber 1997). 'Tainung #2' stalk yields averaged 13.8 tonnes (t)/ha in the 2-yr study and 21.8 t/ha in the 3-yr study. The USDA has also developed 'SF-459', that produces superior stalk yields compared to other cultivars, if the soils are infested with certain detrimental nematodes (Cook et al. 1995). The length of the growing season, the average day and night temperatures, and adequate soil moisture are considered the key factors affecting kenaf yields. Dry land stalk yields normally range from 11 to 18 t/ha, depending on the previously listed production factors.

The leaf yields and leaf biomass percentages are also important considerations when selecting cultivars for kenaf forage production, because the leaves are the primary source of protein (Webber 1993a). Scientists have reported differences among cultivars for stalk and leaf biomass percentages (Webber 1993a; 1993b) and whole plant protein yields (Webber 1993a; Bhardwaj and Webber 1994). For example, Webber reported that '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 (1993b). These stalk and leaf biomass and leaf percentages can also be greatly affected by plant maturity at harvest.

Plant Maturity

Kenaf plant maturity at harvest not only influences the total biomass harvested but also the composition and quality of the plant components. In a 3-yr field study at Lane, Oklahoma with 'Everglades 41', plants were harvested at either 60, 90, 120, or 150 days after planting (DAP) (Bledsoe and Webber 2001). Harvest age did not significantly affect plant populations, but did have a significant affect on all other yield parameters. Averaged across years, the total biomass yields increased from 60 DAP (5.7 t/ha) to 150 DAP (21.0 t/

ha). Although the growth rates did level off or even decrease after 120 DAP, the significant increase in stalk yields after 120 DAP justify the additional 30 days of growth for stalk production. Stalk yields ranged from 3.8 mt/ha for 60 DAP to 19.3 mt/ha for 150 DAP. The percentage of leaf biomass (32%, 60 DAP to 12%, 150 DAP), and leaf digestible protein (18.3%, 60 DAP to 15.5%, 150 DAP) decreased with each harvest date. Leaf yields increased from 2.4 t/ha (60 DAP) and 4.0 t/ha (90 DAP) to 4.4 t/ha at 120 DAP and then decreased to 3.9 t/ha for the 150 DAP harvest.

Additional research evaluating kenaf as a potential forage crop also determined that the age of the plant at harvest influenced 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 150 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 protein during the second harvest was equal to or greater than protein from the first harvest.

Seed production and the plant's composition at seed harvest are closely related, and must be balanced to maximize both seed yields and seed harvesting efficiency. Seed production strategies are affected by the cultivar to be reproduced, the production location and latitude, and the cultural practices. The first issue to be addressed is cultivar photosensitivity, whether ultra-early, early to medium, or late maturing. The best yielding fiber cultivars for the US belong to the early to medium maturing group, which includes such cultivars as 'Everglades 41', 'Everglades 71', 'Tainung #1', 'Tainung #2', 'SF 459', 'N7', 'Cuba 108', and 'Cubano'. 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 US for these cultivars is limited to areas that are unlikely to freeze, southern Florida, lower Rio Grande Valley of Texas, and southern-most areas of Arizona and California (Scott 1982). Seed for these cultivars can also be reproduced in Mexico and Central America.

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 attempting to produce the greatest seed yields from plants that might be 6 m tall and/or greatly branched, it is more desirable to harvest less seed from single stalk plants that are only 1.8 to 2.4 m tall. To produce maximum seed yields on shorter plants, the growing season is shortened by delaying planting to only 30 to 40 days prior to floral initiation. For the photosensitive fiber cultivars grown in the US this would entail planting the kenaf between August 1 to mid August, 30 to 40 days prior to floral initiation during mid September. Under the delayed planting method for seed production, researchers and producers have reported successful efforts to produce large seed yields in southern Florida, 1,919 kg/ha (Seale et al. 1952; Joyner and Wilson 1967), southern Texas, over 1,013 kg/ha (Scott 1982; Cook and Scott 1995), and Mexico, 997 kg/ha (Mullens 1998). Each of these locations has also reported the willingness to trade off seed yields for harvest efficiency.

Plant Populations

Plant populations can also have a tremendous affect on the kenaf yields and plant composition. For most fiber production situations, final plant populations of 185,000 to 370,000 plants/ha are desirable for maximum stalk yields and the production of single stalk plants with little or no branching. To achieve the middle range of plant populations requires about 8 kg/ha of seed (corrected to 100% germination). Research has shown that when plant populations drop below the 185,000 plants/ha stalk yields usually decrease (Higgins and White 1969). At low plant populations the crop produces plants with multiple branches with a greater percentage of leaves, 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 for 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.

Plant population and row spacing can also affect seed yields and plant composition, by affecting the number of seeds, seed capsules, and branches/plant (Crane and Acuna 1945; Joyner and Wilson 1967; Scott 1982; Scott and Cook 1995; Mullens 1998). Crane and Acuna (1945) reported greater branching, increased seed capsules, and seed yields per plant as the distance between plants increased (decreased plant populations). And although individual plant yields increased with lower plant populations the yield per hectare was greater with higher plant populations. This research clearly demonstrated the advantage of greater plant populations, whether comparing seed yields within planting dates or across planting dates. The greatest seed yields in this study in Cuba were produced with an Aug. 24 planting date with a 51-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 'Everglades 71' produced the greatest seed yields (1,910 kg/ha) with the greatest plant populations (472,312 plants/ha), 18-cm row spacing with 12.7 cm between plants within the row. The lowest seed yields, 1,163 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. Researchers in Cuba (Crane and Acuna 1945) and Florida (Joyner and Wilson 1967) both reported an inverse relationship between the number of seed capsules per plant and seed yield per unit area. As the row spacing increased, seed capsules per plant increased and seed yield per unit area 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 and Cook (1995) and Scott (1982) report that Rio Farms, Inc. uses either single 76-cm row spacings or double rows on 102-cm beds (2 rows 25 cm apart on 102-cm beds), with a target plant population 197,680 to 304,800 plants/ha, irrespective of the row spacing. They reported conditioned seed yields from 338 to over 1,013 kg/ha, averaging just slightly less than 676 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 increased the plant populations in 51-cm rows by decreasing the distance between plants from 5.1 to 7.6 cm (387,452 to 258,220 plants/ha) down to 3.8 to 5.1 cm (516,439 to 387,453 plants/ha).

Soil Fertility

Soil fertility can also significantly affect the kenaf yield components (stalks, leaves, and seed). In research in Florida comparing differences in kenaf stalk production and fiber content between a highly organic Everglades peat soil and a low organic sandy soil, it was 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 (Pate et al. 1954). In a two-year soil fertility study in Oklahoma using five nitrogen application rates (0, 56, 112, 168, and 224 kg N/ha) on a fine sandy loam soil, it was determined that stalk yield tended to increase as N application rates increased up to 168 kg N/ha. However, at 224 kg N/ha a significant reduction in stalk yield occurred compared to the 168 kg N/ha level (Webber 1996). In the Oklahoma study excess N application was detrimental to stalk yield and promoted leaf yields.

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). Researchers 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 reported that seed production on rich soils or high fertilizer applications complicated seed harvest by increasing plant vegetation and plant height. As a result, Mullens (1998) suggested 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).

PLANT COMPONENT PARTITIONING AND COMPOSITION

Yield component research with five kenaf cultivars in Oklahoma over a two year period produced plants at harvest (161 DAP) which averaged 26% leaves and 74% stalks by weight (Webber 1993b). In the same research the kenaf stalk's average composition was 35% bark and 65% woody core by weight (Fig. 1). The bark of the kenaf stalk contains the long fiber strands that are composed of many individual smaller fibers, normally called bast fibers. These individual bast fibers, held together by lignin, are the building blocks of the bark fiber strands, which historically were used to make the cordage products. The woody core material of the stalk, the portion remaining when the bark is removed, contains core fibers. The individual bast fibers are longer and thinner than the individual shorter, thicker core fibers. Whole stalk kenaf (bast and core fibers) has been identified as a promising fiber source for paper pulp (Nieschlag et al. 1960; White et al. 1970). The kenaf fibers, bast and core, can be pulped together or separated and pulped individually depending on the pulping process and the paper pulp to be produced (Kaldor et al. 1990).

Whole Stalk

Whole stalk kenaf can be pulped by kraft, soda, neutral-sulfite, sulfate, mechanical, chemimechanical, thermomechanical, and chemithermomechanical processes (Clark and Wolff 1962; Bagby 1989). Whole-stalk kenaf pulps have been processed into high quality bond, surface sized, coated rawstock, and newsprint papers (Clark et al. 1971; Bagby et al. 1979; Bagby 1989). Commercial presses have printed on kenaf paper using letterpress, offset, rotogravure, flexograph, and intaglio techniques (Bagby 1989). The combined (bast and core) bleached fiber yield from chemical pulping is about 46% by weight (Kaldor et al. 1990). Whole stalk kenaf can also be used in corrugated medium (Kugler 1988).

The whole-stalk plant material can also be used in non-pulping products such as building materials such as particleboard (Webber et al. 1999a), and within injection molded and extruded plastics (Webber and Bledsoe 1993). Unlike the pulping process with whole-stalk plant material which yields under 50% (46% by weight), the use of non-pulped whole-stalk material yields nearly 100% usable material. The difference is the result of the intentional removal of non-fibrous materials such as lignins and sugars during the pulping process, whereas the removal of these intercellular materials is not required for the non-pulped products.

Bark and Bast Fiber

When bark material was chemically pulped without the core, it produced a 57% yield of bast fiber (Karlgren et al. 1991). On a whole-stalk dry weight basis, the bark comprises 17.4% to 28.6% (Nieschlag et al. 1961; Karlgren et al. 1991). The individual bast fibers are up to 5.0 mm long (Clark and Wolff 1965) averaging 2.6 mm in length and 20 mm in width (Nieschlag et al. 1961). Chemical bast pulp is well suited for specialty papers, such as high quality stationery or filter paper. Bast pulp, compared to softwood pulp, has a similar tensile strength, but greater tear strength and bulk fiber; thus it could serve as a replacement for softwood pulp (Kaldor et al. 1990). Pulping kenaf fibers (bast and core) can benefit the environment because the process requires fewer chemicals and less energy compared to standard pulping processes for wood fibers. The kenaf fibers can also serve as a virgin fiber for increasing recycled paper quality and paper strength.

Although the kenaf bark fiber strands were once only considered for use as a cordage fiber in such



Fig. 1. Kenaf stalk with bark and core material.

products as rope, twine, carpet backing, and burlap (Wilson et al. 1965), a diverse list of additional uses have developed for the bark fiber strands (Fig 2). These include use in automobile dashboards, carpet padding, corrugated medium (Kugler 1988), as a “substitute for fiberglass and other synthetic fibers” (Scott and Taylor 1988), textiles (Ramaswamy and Boyd 1994), and as fibers for injection molded and extruded plastics (Webber and Bledsoe 1993). Kenaf bark fiber strands are presently in commercial use in other environmentally friendly products such as fiber lawn mats impregnated with grass seed, and spray-on soil mulches for use along highway rights-of-way or construction sites to prevent soil erosion from water and wind.

Woody Core and Core Fibers

Chemical pulping of the woody core will yield about 41% core fiber from the original woody portion of a kenaf stalk (Karlgren et al. 1991). The core fibers make up from 20% to 40% of the entire stalk by weight (Nieschlag et al. 1961). The average length of the core fibers range from 0.49 to 0.78 mm long (Nieschlag et al. 1961; Adamson and Bagby 1975; Kaldor et al. 1990) with a mean length of 0.6 mm and an average diameter of 37.4 μ m (Nieschlag et al. 1961). The core pulp, compared to hardwood pulps, has a lower tear strength, but greater tensile and burst strength (Kaldor et al. 1990).

Due to the high absorbency of the woody core material, researchers have investigated the use of kenaf as an absorbent (Goforth 1994), as a poultry litter and animal bedding (Tilmon et al. 1988), as a bulking agent for sewage sludge composting (Webber 1994), and as a potting soil amendment (Laiche and Newman 1994; Webber et al. 1999b) (Fig 3). In addition to the above core products, which are all now available in the market place, several kenaf core products are available which are successfully used for toxic waste cleanup, oil spills on water, and the remediation of chemically contaminated soils.

Protein and Feed Content

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; Suriyantratonng 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; Suriyantratonng 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 (Suriyantratonng 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).



Fig. 2. Kenaf bark fiber strands; fiber strands after harvesting with a forage chopper (left), retted combed fiber strands (center), and fiber strands compressed into a square cube.



Fig. 3. Core fiber material; small (left), medium (second from left), large (third from the left), and compresses into a square cube.

Leaf Essential Oils and Volatiles

The kenaf plant may be a source of naturally occurring allelopathic chemicals that prevent or inhibit weed seed germination and weed growth, and therefore could provide a safe and economic means of inhibiting weed competition in vegetable and agronomic crops. Initial research using whole-stalk kenaf as a mulch in vegetable production, reduced weed populations and provided initial evidence that kenaf plant material might have allelopathic properties (Russo et al. 1997a). Extracts from kenaf “whole-plant” (stalks and leaves) reduced germination of redroot pigweed (*Amaranthus retroflexus* L., Amaranthaceae) by 50% to 70%, and to a lesser extent that of Italian ryegrass (*Lolium multiflorum* Lam., Poaceae) and tomato (*Lycopersicon esculentum* Mill., Solanaceae) (Russo et al. 1997b). Further research determined that it was the extracts from the leaf portion of the kenaf plants that decreased germination of redroot pigweed, tomato, Italian ryegrass, and cucumber (*Cucumis sativus* L., Cucurbitaceae) (Webber et al. 2000). Kobaisy et al. (2001) analyzed the composition of the essential oil of the kenaf leaves and the oil’s natural ability to inhibit plant (allelopathy, natural herbicidal activity) or fungal (fungicidal activity) growth. Fifty-eight components were identified and characterized from the essential oil and it was determined that the essential oil was phytotoxic to lettuce (*Lactuca sativa* L., Asteraceae) and bentgrass (*Agrostis stolonifera* L., Poaceae) and that it also exhibited antifungal activity against *Colletotrichum* species (*Colletotrichum fragariae*, *C. gloeosporioides*, and *C. accutatum*), which often cause anthracnose symptoms. The research confirmed the allelopathic activity and discovered the antifungal properties of the essential oil. Of the 58 essential oil components identified, the major components included (E)-phytol (28.16%), (Z)-phytol (8.02%), n-nonanal (5.70%), benzene acetaldehyde (4.39%), (E)-2-hexenal (3.10%), and 5-methylfurfural (3.00%).

Earlier researchers (Osman et al. 1976) also evaluated the composition of the kenaf leaf, specifically the leaf volatiles. The authors reported that the presence of 10 components, including ethyl alcohol, isobutyl alcohol, limonene, phellandrene, R-terpenyl acetate, citral, and four unidentified components (Kobaisy et al. 2001).

Seed

Seed from kenaf may provide an excellent oil resource (Fig 4). Mohamed et al. (1995) determined the quality and quantity of oil, fatty acids, phospholipids, and sterols in seed of nine kenaf genotypes (‘Cubano’, ‘Everglades 41’, ‘Everglades 71’, ‘GR2563’, ‘Guatemala 48’, ‘Indian’, 178-18RS-10, ‘Tainung #1’, and ‘Tainung #2’). Oil content ranged from 21.4% to 26.4% with a mean of 23.7%. Total phospholipids ranged from 3.9% to 10.3% of the oil, with a mean of 6.0%. Total sterol percentage was similar to that reported for soybean and cottonseed oil. Mean sterol content was 0.9% and ranged from 0.6% of the total oil for 178-18RS-10 accession to 1.2% for ‘Everglades 71’. Palmitic (20.1% of the total fatty acids), oleic (29.2%), and linoleic (45.9%) were the major fatty acids, and palmitoleic (1.6%), linolenic (0.7%), and stearic (3.5%) were the minor components. Medium (C_{12} – C_{14}) and long (C_{22} – C_{24}) chain fatty acids were less than 1% of the total phospholipids. Sphingomyelin (4.42% of the total phospholipids), phosphatidyl ethanolamine (12.8%), phosphatidyl choline (21.9%), phosphatidyl serine (2.9%), phosphatidyl inositol (2.7%), lysophosphatidyl choline (5.3%), phosphatidyl glycerol (8.9%), phosphatidic acid (4.9%), and cardiolipin (3.6%) were identified in the nine genotypes. Phosphatidyl choline, phosphatidyl ethanolamine, and phosphatidyl glycerol were the dominant phospholipids. Kenaf’s relatively high oil content and its similarity to cottonseed oil suggest that the seed oil may be used as an excellent source of edible oil for human consumption. In addition to potential advantages of a longer shelf life, the sterol emulsions could be used in reducing hypercholesterolemia. The variation among genotypes also indicates potential for genetic improvement in oil yield and quality.



Fig. 4. Kenaf seed and seed oil.

The high oil content of the kenaf seed can also affect the seed's viability if not stored correctly. Certain 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 high 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).

SUMMARY

For six thousand years the long bark fiber strands of kenaf have been a valuable and important resource for use in cordage products (twine, rope, and sackcloth), and although synthetic fibers now often decrease the use of the bark fiber strands in cordage material, the newer and more complete usefulness of the entire kenaf plant continues to make kenaf a crop of world wide interest. The useful kenaf plant components include the stalks (bark and core), leaves, and seeds. The combined attributes of these components (bark fiber strands and bast fibers, the core material and individual core fibers, and leaf and oil chemistry), provide ample potential product diversity to continue use and development of this crop. Beyond the diverse new uses for kenaf including its utilization in paper products, building materials, absorbents, textiles, and livestock feed, 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.

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