DIALLEL AND STABILITY ANALYSIS OF KENAF (*Hibiscus cannabinus* L.) IN SOUTH AFRICA

By

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DECLARATION

I declare that the thesis hereby submitted by me for the Masters degree at the University of the Free State is my own independent work and has not previously been submitted by me at another university/faculty. I further more cede copyright of the thesis in favour of the University of the Free State.

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DEDICATION

This piece of work is dedicated to my parents,

who sent me to school and encouraged me to fulfill my dream

谨以此文献给我敬爱的父母和伟大的祖国

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Chapter 1

Introduction

Kenaf (*Hibiscus cannabinus* L. 2n=36) is an annual herbaceous crop of the *Malvaceae* family, which is known for both its economic and horticultural importance. Most researchers agree that the origin of Kenaf is in Africa, where diversified forms of the kenaf species and its related species in the Hibiscus genus, including roselle (*Hibiscus sabdariffa* L.), are found growing widely in many countries of eastern Africa (Dempsey, 1975; Li, 1990; Cheng, 2004).

Kenaf is one of the most important fiber crops in the world. It has been cultivated and used as cordage crop to produce twine, rope, gunny-bag and sackcloth for over six millennia (Dempsey, 1975; Charles, 2002). New applications of kenaf have been developed, such as pulping and papermaking, oil absorption and potting media, board making, filtration media and animal feed (Sellers and Reichert, 1999; Cheng, 2001). Among so many applications, pulping and papermaking have drawn tremendous attention and look more and more promising for the future (Clark, 1962; Kano, 1997). Kenaf is commercially cultivated in more than 20 countries, particularly in India, China, Thailand and Vietnam (FAO, 2003).

Much research has been done in kenaf, and a large number of varieties have been developed to meet the demands of high-fiber-yielding and disease-resistant kenaf in the recent decades (Dempsey, 1975; Bitzer, 2000). Although kenaf originated from Africa, its production in Africa is very low. In 2002, total production of Africa was just 2.9% of the world production (FAO, 2003). Some African scientists classified kenaf as weed. Kenaf has been investigated in South Africa with a view to commercial production in recent years. It is necessary to evaluate the stability of cultivars and this work could give references to the Kenaf production in South Africa.

Kenaf expresses a high degree of heterosis (Dempsey, 1975; Li, 2000). After solving the problem of manual pollination, many hybrid cultivars have been released and utilized in production (Li, 2002). Kenaf hybrids are very popular in some countries, like China, Russia, and Thailand. About 1000 tonnes of hybrid seed is sold in China every year (IBFC, 2005).

Combining ability is the ability of a parent to produce inferior or superior combinations in one or a series of crosses (Chaudhary, 1982). Many commercial cultivars, besides their high agronomic performances, perform poorly in the F1 generation, due to genetic hindrances in diverse cross combinations. Consequently, crossing in a diallel fashion is the only specific and effective technique for the measurement, identification and selection of superior genotypes (Mohammad, 2003). Estimating combining ability, diallel analysis is the first step in most plant-breeding programs aimed at improving yield and other related parameters (Pickett, 1993; Griffing, 1956).

Plant breeding aims to improve crop production either within a given macro-environment or in a wide range of growing conditions. An understanding of environmental and genotypic causes of G X E interaction is important at all stages of plant breeding. This can also be used to establish breeding objectives to identify ideal test conditions, and to formulate recommendations for areas of optimal cultivar adaptation (Jackson *et al.,* 1998).

The aims of this study were:

1. To study the genetic variability for agronomic characteristics in kenaf.
2. To analyze the stability and genotype x environment interaction of kenaf germplasm in targeted production areas.
3. To investigate the combining ability of cultivars and heritability of traits by full diallel analysis.

Chapter 2

Literature review

2.1 Botanical taxonomy and growth conditions

2.1.1 Classification

Kenaf (*Hibiscus cannabinus* L.) is a short-day, annual, herbaceous plant cultivated for the soft bast fiber in the stem. It belongs to the *Malvaceae*, a family notable for both its economic and horticultural importance (Dempsey, 1975). The genus *Hibiscus* is widespread with more than 400 species. It is divided into six different sections: *Furaria, Alyogen, Abelmoschus, Ketmia, Calyphyllia,* and *Azanza*. Kenaf is classified taxonomically in the *Furaria* section. This section includes about 40-50 species (Su *et al*., 2004). Kenaf is closely related to cotton (*Gossypium hirsutum* L.), okra (*Hibiscus esculentum* L.) and hollyhock (*Althaea rosea* L.). In some places, roselle (*Hibiscus sabdariffa* L.) is also called kenaf.

In the Furaria section, the chromosome number is a multiple of 18 in all the species, from 2n=36 to 2n=180. The diversity in number of chromosomes and genomes found in this section is not common in the plant world. This chromosomal diversity is reflected in the high levels of morphological and physiological diversity in the crops (Wilson, 2003; Su *et al*., 2004).

According to Dempsey (1975), there are more than 129 common names for kenaf worldwide. For example mesta (India, Bengal), stokroos (South Africa), Java jute (Indonesia), ambari (Taiwan) (Li, 1980; Liu, 2000).

2.1.2 Botany

Kenaf has a high growth rate, reaching heights of 4-6 m in about 4-5 months and its yields of 6-10 tonnes of dry mass per acre each year, is generally 3-5 times greater than the yield for the southern pine tree which can take from 7-40 years to reach harvestable size.

Leaves

Kenaf plants produce two general leaf types, divided and entire. 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. The divided (split-leaf) cultivars have deeply lobed leaves with 3, 5, or 7 lobes per leaf; the entire leaf cultivars produce leaves that are shallowly lobed, and are basically cordate (heart-shaped). The divided leaf characteristic was found to be dominant and the entire leaf shape was recessive (Jones *et al*., 1955).

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 younger 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 the production of the first divided leaf (Charles, 2002). 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 gland are visited in large numbers by wasps (Jones *et al*., 1955).

Stalks

Kenaf has erect, branched or unbranched, stalks reaching a height of 1-4 m, and either slender green, red, or purple prickly. The stalks of the kenaf are generally round, and depending on the variety, thorns on the stalks are quite tiny. It consists of two distinct fiber types: the outer, bast fibers which comprise about 35% of the stalk dry weight and the inner, core fibers that comprise about 65% of the stalk's dry weight (Lin *et al.*, 2004). Liu (2000) and Chen *et al.* (1995) reported composition of the stalk (Table 2.1 and Table 2.2).

Table 2.1 Details of the dimensions of the component cells in the bast and core fractions of the stalk (Liu, 2000)

Type of fiber	Cell length (mm)	Cell width (micron)	Cell wall thickness (micron)	Lumen width (micron)
Bast	1.8-4.0	14-24	3.8-8.6	6.6-12.8
Core	0.4-1.0	22-37	4.8-8.2	16.5-22.7

Table 2.2 Details of the composition of the whole stalks (Chen *et al.*, 1995)

Type of fiber	Ash %	a-Cellulose %	Semi-cellulose %	Lignin %
Bark	5.5-8.3	53.0-57.4	NA	5.9-9.3
Core	2.9-4.2	51.2	NA	17
Whole stalk	2.1-6.5	47.3-57.3	31.5-38.4	4.7-16.1

Flowers

Kenaf has large showy, light yellow or creamy colored flowers that are bell-shaped and widely open. The flowers of many cultivars have a deep red or maroon colored center. The flowers are 8-13 cm in diameter with five petals and are borne singly in the leaf axis along the stalk and branches. They usually open just before daybreak, begin to close about midday, and are closed by mid-afternoon never to open again. Within the corolla, the staminal column, with its short stamens, surround the style. The anthers release pollen about the time the flower opens, and the style emerges shortly thereafter. The five-part stigma expands; the lobes become turgid but do not touch the anthers. The corolla closes spirally so that the anthers are pressed into contact with the stigma, and, if cross-pollination has not occurred, self-pollination may result (Howard and Howard, 1911).

The pollination requirement of kenaf is well described. Pate and Joyner (1958) stated that kenaf has been classified on several occasions as a self-pollinated crop, but that more recently it has been classified as an often cross-pollinated crop. 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 cross-pollination ranged from 2 to 24%.

Seed and seed capsules

Following pollination, a pointed, ovoid, seed capsule is formed that is about 1.9 to 2.5cm 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 coming in contact with human skin. Each capsule contains five segments with a total of 20 to 26 seeds/capsule (Dempsey, 1975). Kenaf seeds are grayish brown, approximately 6 mm long and 4 mm wide with 35,000 to 40,000 seeds/kg. Once pollinated, the seeds require an additional 60-90 days of frost free conditions to mature (Tamargo and Jones, 1951).

About 20% of the volume of kenaf seed is oil, very similar in composition to that of cotton. Freshly harvested kenaf seed has a germination percentage of about 98%. However, because of their high oil content, they lose viability rapidly (Dempsey, 1975).

2.1.3 Environmental conditions for kenaf growth

Kenaf has a wider range of adaptation to climatic conditions than other fiber crops grown for commercial use. It has wide ecological adaptability (Liu, 2003). In general, kenaf is grown between 45^{o} N and 30^{o} S latitudes with a mean relative humidity range of 68-82% (Ustinova, 1938). It is found naturally growing in Africa from the Equator to the limits of about latitude 30^{o} North and South altitude up to 1.25 m. Kenaf will not tolerate frost, and the mean growing temperature ranges from 22.6^{o} C to 30.3^{o} C. During the growing season, a well-distributed rainfall of 100-125 mm per month is necessary for proper kenaf growth (Dempsey, 1975). Crane (1947) reported that 500-625 mm over a period of 5 to 6 months is essential for the successful production of kenaf fiber.

Kenaf will grow well and produce high fiber yield when grown on an extremely wide range of soils, including acid peats, alluvial silty loams, sandy loams, sandy clay loams, clay loams, alkaline and saline desert soil, latasols and many other soils. The principal requirement is that the soils possess good drainage, although it will tolerate flooding in the last stages of growth (Dempsey, 1975). Kenaf is better adapted to poor soils than most of commercial crops. It can be planted on marginal land. Because the soil origin, composition, and colour do not affect kenaf, the crop will

grow on a wide range of soil types. But there should not be limiting factors such as a trace deficiency, alkalinity, or a hard pan. Fertile, well-drained soil is best for kenaf (Dempsey, 1975).

Most varieties of kenaf are photoperiodic, being critically influenced by the length of daytime period. Regardless of the time of planting, most improved kenaf varieties remain vegetative until the daylight period falls below 12.5 hours, then flowering takes place. Therefore, it is very important that plantings for fiber be made early enough to allow the crop to produce maximum growth before the critical daylight period is reached. 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; Charles, 2002).

2.2 Origin, history and species

2.2.1 Origin

It is accepted by most authors that kenaf originated from sub-Saharan Africa, where diversified forms of the kenaf species are found growing widely in many countries of Eastern Africa (Wilson and Menzel, 1964; Dempsey, 1975; Li, 1990; Cheng, 2004). Based on field surveys and investigations, Wilson and Menzel (1964) indicated that kenaf was domesticated around 4000 BC in the Sudan region. Chen *et al.* (2004) identified 23 accessions of kenaf germplasm by AFLP and reported that their AFLP analysis strongly supported the theory that kenaf originated in Africa, then disseminated from Africa through Asia to Central and North America.

2.2.2 History

After it was domesticated and used in Africa for over six millennia, kenaf was first introduced to India in the last 200 years, Russia started producing kenaf in 1902. Kenaf came into mainland China from Taiwan at the beginning of 1900 (Dempsey, 1975; Charles, 2002; Li, 2002). Kenaf was cultivated commercially as a fiber crop in Asia and the USSR in the 1930's. During the Second World War, as foreign fiber supplies were interrupted, kenaf research and production was started in the U.S. to supply cordage material for the war effort (Wilson and Margarety, 1967).

In the 1950's, researchers were evaluating more than 500 plant species to fulfill the increasing future fiber demands in the USA. Kenaf was identified as an excellent cellulose fiber source for a large range of paper products (Nelson *et al*., 1962). Currently, many countries pay more attention to kenaf research and cultivation because of its high biological efficiency and wide ecological adaptability. Kenaf has been called "the future crop" (Mazumder, 2000; Cheng, 2001).

2.2.3 Species

Germplasm

Genetic resources play a very important role in breeding superior varieties and promoting production of kenaf (Su *et al.,* 2004). Genetic resources collection is a basic function of kenaf research and breeding. Edmonds (1991) reported that wild kenaf varieties have many excellent genes, such as resistance to anthracnose disease (*Colletotrichum hibisci* Poll), good fiber quality, drought-resistance, etc., that can be used for kenaf improvement.

Most governments focus on collection of kenaf germplasm, and put forward strategies of sustainable development and utilization of genetic diversity. China has the biggest kenaf genebank in the world, with 1800 species. 69% of them are from 31 countries (Su *et al*., 2004).

Varieties and cultivars

Although kenaf is a short-day crop, its cultivars differ in their sensitivity and response to day-length (Charles, 2002). Dempsey (1975) classified kenaf cultivars into three groups by maturity: ultra-early, early to medium and late-maturing.

1) Ultra-early group: include Russian and Korean cultivars. This group of cultivars was developed to grow at latitudes greater than 37 N or 37 S that mature in 70-100 days. Compared to other groups, these cultivars have higher seed yields, shorter plants and lower fiber yields. If these cultivars are grown at lower latitudes, they will flower even earlier and get even lower fiber yields.

2) Early to medium group: they are photosensitive cultivars and initiate flowering when the day-length falls to 12.5 hours. Ideally suited for production between latitudes of 10 to 27 N or S, most of US and Indian cultivars, such as “Cuba108” ,”Everglades 41”, “Everglades 71” belong to this group (Scott 1982). They need 100-120 days to mature. The plant height ranges from 2.5 to 3.5 m and dry fiber yields range from 1 to 4 t/ha.

3) Late maturing group: these cultivars are photo insensitive, late maturing and require 140 or more days to mature. Commonly, they grow in latitudes between 10 N to 10 S. For the longer vegetative period, those cultivars have high fiber yield and excellent fiber quality. Most of these cultivars originated from the crossing of different cultivars. If grown for seed production, it would reduce the stalk and fiber yields (Dempsey, 1975). Cultivars “Guatemala 4”, and “Cuba 2032” belong to this group.

2.3 Importance of kenaf

2.3.1 Production of kenaf

Kenaf with jute (*Corchorus capsularis* and *Corchorus olitorius* L) and roselle are the second most important vegetable bast fiber crops next to cotton (IJSG, 2004). Kenaf is cultivated in more than 20 countries of the world (FAO, 1998). Ninety percent of the sown area and more than 95 % of total production are from China, India and Thailand (FAO, 2003). Kenaf is also a commercial crop in Russia, Vietnam, Mozambique, Iran, Taiwan, El Salvador, Guatemala, Ivory Coast and Nigeria (Dempsey, 1975).

Table 2.3 Global production of kenaf (,000 tons) (FAO, 2003)

	1990-1992	1993-1995	1996	1997	1998	1999	2000	2001	2002
Africa	10.2	11.6	13.9	14.2	13.8	14.3	12.7	12.5	12.4
America	33.4	32.5	31.0	28.8	27.1	25.4	24.1	23.7	26.7
Near east	6.4	4.9	5.1	5.2	4.2	3.7	3.6	3.6	3.6
Far east	1043.1	819.9	703.9	763.0	500.3	409.1	372.1	393.9	383.7
China	619.3	465.9	364.9	429.5	248.0	164.0	126.0	136.0	130.0
India	227.6	199.8	210.4	198.7	182.2	198.2	198.0	203.4	202.1
Thailand	159.5	128.1	109.3	106.4	47.2	29.7	29.6	29.5	30.0
Vietnam	24.9	17.0	15.0	22.3	14.6	9.4	11.3	14.6	14.6
World	1093.1	869.0	753.9	811.2	545.4	452.5	412.5	433.7	426.4

In 1985, global kenaf production reached an all time high of 2.8 million ton. After this time, kenaf production has shown a declining trend. Now its production is stable around 0.4 million ton. Kenaf is an important cash crop of many developing countries like, China, India, Thailand, and Bangladesh (Liu, 2003).

2.3.2 Uses of kenaf

Kenaf has been planted for handicraft purpose and leaves for food from 4000 BC in Africa. The traditional use of kenaf is:

1) Fiber use

Kenaf has been used mainly to make cordage, rope, burlap cloth and fish net because of its rot and mildew resistance (Cook, 1960). Today, one of the major uses of kenaf is to make a range of paper and cardboard products as a substitute for wood. Because of environmental problems (artificial fiber produce long-time pollution) and increased paper consumption, this application of kenaf fiber has drawn tremendous attention in the world (Bert, 2002).

2) Food use

People plant kenaf in home gardens and eat the scions and leaves either raw or cooked. Dried kenaf leaves have 30% crude protein and is eaten as vegetable in some countries. It also has potential for livestock feed (Zhang, 2003).

New uses of kenaf

1) Medicine

A sort of polysaccharide was extracted from kenaf seeds by Japanese researchers. Mixed into food and fed to mice, scientist found it could reduce the cholesterol of the mice. Further research for human use was done in Japan recently (Cheng, 2001).

2) Food additive

Hosomi (2000) added the dried kenaf-leaves powder into nine kinds of food. He reported it could improve the content of calcium and fiber of the food, the taste of food was not reduced. He reported that kenaf is an ideal food additive and its leaves also can be used as tea.

3) Medium for mushroom cultivation

Use of kenaf core with wood powder as plant medium to produce mushrooms is much better than only using wood powder. Yield could be doubled compared to using only wood powder. Kenaf medium was commercially used in mushroom cultivation in Japan and China (Cheng, 2001). Kenaf potting soil is a substitute for peat moss, a non-renewable resource (Liu, 2003).

4) Oil and chemical absorbents

Kenaf core is strong and absorbent and it can be used to clean up oil spills as well as chemicals. For its low density, once oil is absorbed, the product floats on the surface, which makes collection easier. Kenaf core is also non-toxic, non-abrasive and is more effective than classical remediants, like clay and silica (Sameshima, 2000).

5) Natural fiber/plastic compounds

Kenaf natural fiber/plastic compounds are light and easy to process. They could replace glass-reinforced plastics in many cases. Kenaf compound panels have the mechanical and strength characteristics of glass-filled plastics. At the same

time, they are less expensive and completely recyclable in many instances (Kano, 1997), they can be used in the automotive industry, construction, housing, and food package industry (Zhang, 2003).

6) Environment cleaning

Kenaf can absorb CO_2 and NO_2 3-5 times faster than forests, and its deep roots can improve the soil. It can clean the environment efficiently (Lam, 2000). In some Japanese cities, kenaf was planted by government to improve the air quality.

7) Animal bedding and poultry litter

Kenaf bedding has superior absorbency, is labour saving, it costs less than most traditional litter and bedding products comprised of wood shaving, saw dust or shredded paper (Li, 2002).

2.3.3 Increasing demand for kenaf

In the 21st century, people will require more natural products instead of synthetic ones, owing to the attention to environmental protection and self-health. The demand for fibers for clothing is expected to rise from the current 60 million to 130 million tonnes per year before 2050 (Kozlowski, 1996). Kenaf is an alternative natural fiber source other than cotton fiber. The clothes made from kenaf fiber do not crease easily and quickly diffuse heat, so they are more comfortable than clothes made from cotton. In general, kenaf fiber makes a high grade summer cloth (Cheng, 2001).

Because of the rapidly increasing consumption of paper, many countries show a great interest in research and development of kenaf as alternative material in the papermaking industry. The FAO stated that between 1950 and 1988, the world demand for pulp and paper grew at an annual average rate of 4.7%. It is estimated that demand for pulp and paper will rise to 620 million tonnes in 2010 (Liu, 2003). Several kenaf pulp making factories have been set up in many countries, like the USA, China and Japan (Liu, 2000). In 1994, the world production of paper pulp made from non-wood material, including kenaf, reached 12.5 million tonnes.

2.3.4 Advantages of kenaf for pulp and papermaking

Environment friendly alternative

Because little chemicals are required in kenaf pulping than wood pulping, it gives the papermaking industry a “pollution solution”. Hydrogen peroxide is used as bleach. Instead of chlorine, which is a main environment concern of paper mills. Pulping for kenaf uses less energy than classical wood pulping due to the low lignin content of kenaf. So the treated wastewater from paper mills can be used for irrigation. Kenaf can be either pulped alone or blended with recycled paper or used as virgin pulp (Liu, 2003).

High paper quality

Kenaf fiber is considered fit for making speciality paper. Kenaf paper is stronger, whiter, longer lasting, more resistant to yellowing and has ink adherence better than wood paper (Liu, 2003).

2.4 Kenaf fiber and fiber quality

2.4.1 Kenaf fiber

Natural kenaf fiber is like bundle of lignocellulose fibers. The fiber size depends on the number of ultimate cells in each bundle. Kenaf single fibers are 1-7 mm long and about 10-30 microns wide. The length of kenaf fibers is shorter at the bottom of the stalk and longer at the top. The increase in length from the bottom to the top was found not to be gradual, but S-shaped (Rowell and Han, 1999). Fiber length grew in the early part of the plant cycle, and reduced again as the plants mature (Chen *et al.*, 1995).

Kenaf fiber yields are highly variable, as percentage retted fiber in the fresh plant and kilograms per hectare of the retted fiber. The dry fiber yield is 5-6% of the fresh stems, and this equals 18-22% of the dry plant. Commonly the dry yield is 1-2 ton/ha, but it can reach 3-3.5 ton/ha under ideal conditions (Dempsey, 1975).

2.4.2 Kenaf fiber quality

Ramaswamy and Boyd (1994) stated that the following characteristics can be used as criteria to determine the kenaf fiber quality:

1) Reed length
2) Bundle breaking tenacity
3) Elongation at break
4) Color and luster
5) Gum content

Reed length is the total length from base to tip of the decorticated kenaf stalk before and after processing. This criterion may be important for fiber yield when the intended use is for products, such as ropes and cordage (Zhang, 2003).

Bundle breaking tenacity is defined as the load required to break a fiber bundle of fixed length and weight. As a measure of fiber quality, it would provide quick, accurate results depending on linear density of the bundle. It establishes the possibility of extracting fibers for large scale production of fibers (Ramaswamy and Boyd, 1994).

Elongation is the amount of a fiber bundle before it breaks. It is an important measure to indicate strength. Color and luster are important properties depending on the fiber end use. Luster has a positive correlation with strength. Gum content refers to the total tax, oil, lignin, and other hemicellulosic material. Residual gum content, the amount of gum left after processing, affects the fineness of fibers. This ultimately determines the success of using these fibers in a fine, woven textile structure (Zhang, 2003).

In commercial plants, many factors will influence the fiber quality

1) Variety

   Different varieties have different fiber quality. Dempsey (1975) reported that the fiber of kenaf varieties varies from 4-5% in the fresh plant. He also stated that the late maturing group cultivars could produce better fiber than early maturing ones.

2) Environmental conditions

Favorable cultivation conditions could lead to better fiber quality. Fiber quality of kenaf grown on sand is better than that of plants grown on peat soil (Pate *et al.,* 1954). Satisfactory levels of fertility, temperature, plant density and irrigation could improve the fiber quality (Dempsey, 1975).

3) Harvesting

The highest quality fiber is obtained when kenaf is harvested during the beginning of the flowering period (Duke and Ducellier, 1993). Higgins and White (1970) indicated that fiber quality was obviously reduced after it bloomed (Moreau *et al.,* 1995).

4) Retting and processing

There are two methods of retting: bacterial retting and chemical retting. Pate *et al.* (1954) reported that the bacterial method is better than chemical, because it gives better fiber quality and lower pollution.

2.5 Advances in kenaf breeding

Kenaf breeding is accompanied with its dissemination and utilization. The earliest literature reported research of kenaf already from the18th century (Dempsey, 1975; Pace *et al*., 1998). Before the 1900's, kenaf cultivars were already selected (Howard and Howard, 1911). After the 1940's, a large number of kenaf cultivars was released to meet the demands for high-fiber-yield and disease-resistance (Dempsey, 1975; Bitzer, 2000).

2.5.1 Disease-resistance breeding

Dempsey (1975) listed all of the principle diseases of kenaf. They are anthracnose, stem and seedling rot, collar rot, leaf spot, powdery mildew, gray mold, carbon rot. But the most widespread and destructive disease of kenaf is anthracnose. This disease could attack kenaf at any time from emergence to maturity. After 4-6 days of infection, the top of the susceptible plant is killed, and it spreads very quickly.

In the 1950's, this disease occurred in Cuba and destroyed most of the kenaf. After several years of breeding and selection, the highly resistant kenaf cultivars "Cubano",

and “Cuba 108” were released. In China, this disease also devastated commercial production of kenaf. Even the cultivars of the Indian ecotype lost 20-30% yield (Dempsey, 1975). In that time, the disease-resistance breeding followed the strategy of finding resistant material first, like ‘QingPi3”. This was used to make crosses with local cultivars, then select for resistance, stability and release (Wu *et al.*, 2003).

2.5.2 Research and utilization of hybrid kenaf

Heterosis of kenaf hybrids is strongly expressed (Pate and Joyner, 1958; Nelson and Wilson, 1965). In China, hybrid kenaf cultivars are used in commercial production. From 1978, a hybrid breeding program was started in China. Tan (1985) reported that the commercial herbicide “DalaponNa” (CH3CCL3CCNa) can be used as a selective for hybrid seed production, which is revolutionary in hybrid seed production. Then, using hybrid kenaf cultivars on commercial scale is come into reality. Until 2002, more than 30 kenaf hybrid cultivars were used in China. Li (2000) stated that using F2 seed did not reduced the yield sharply. But the F2 seeds cost can be decreased greatly. So the F_2 is also used in commercial production.

Male sterility utilization is now receiving a significant amount of attention. Zhou *et al*. (1996) reported that they sent kenaf seeds to space, and got some male sterile kenaf materials. Deeper research was done by Chinese scientist. More research involving male sterility utilization was conducted in Japan and the USA from the 1990’s (Li, 2002). Lin *et al.* (2004) reported that they released the cultivar “Fuhong 4” by male sterility. It was used in the paper-making industry. The ratio of pulp making was higher than the standard cultivar.

2.6 Diallel analysis

Diallel analysis is the first step in most plant breeding programs aimed at improving yield and other related parameters. Danish animal breeder, Schmidt, first introduced the diallel-crossing concept in 1919 (Pirchner, 1979). Then it was quickly introduced in plant breeding. The diallel is defined as making all possible crosses in a group of genotypes. It is the most popular method used by breeders to obtain information on value of varieties as parents, and to assess the gene action in various characters (Pickett, 1993; Griffing, 1956). Griffing (1956) developed a range of diallel analytical procedures. This should help breeders to develop appropriate selection strategies

and compare heterotic patterns at the early period of hybridization breeding (Le Gouis *et al*., 2002). Four methods can be used 1) Parents, F1's and reciprocals, 2) Parents and F1's, 3) F1's and reciprocals and 4) F1's only. The linear analysis model can be for either fixed or random effects. If the genotypes are highly selected and inbred, then a fixed model for analysis is usually done for applied breeding programs (Agrobase, 2000). In this case the sampling error becomes the residual for testing combining ability mean squares, and estimating variance components and standard errors. When additive and dominance variances are estimated, certain limitations apply: normal diploid segregation, no epistasis, no reciprocal differences, no multiple alleles, homozygous parents, independent gene distribution, no linkage, and an inbreeding coefficient of zero (Griffing, 1956), but these assumptions are rarely fulfilled in practice (Baker, 1978).

2.6.1 Combining ability

Combining ability is defined as the ability of a parent line in hybrid combinations (Kambal and Webster, 1965). It plays an important role in selecting superior parents for hybrid combinations and in studying the nature of genetic variation (Duvick, 1999). It is a powerful method to measure the nature of gene action involved in quantitative traits (Baker, 1978). Sprague and Tatum (1942) introduced the concept of general combining ability (GCA) and specific combining ability (SCA). The authors defined GCA as the average performance of a line in hybrid combinations, while SCA as those instances in which certain hybrid combinations are either better or poorer than would be expected of the average performance of the parent inbred lines included. For random individuals, GCA is associated with additive effects of the genes, while SCA is related to dominance and epistatic effects (non-additive effects) of the genes (Sprague and Tatum, 1942). GCA effects represent the fixable component of genetic variance, and are important to develop superior genotypes. SCA represents a non-fixable component of genetic variation, it is important to provide information for hybrid performance (Sprague, 1966).

Kenaf is considered as a self-pollinated crop (Dempsey, 1975). However, Jones *et al.* (1955) reported rates of out-crossing of 2 to 24%. The independent action of non-allelic genes and absence of multiple allelisms were identified using non-segregating F1 progenies (Pace *et al.,* 1998). Pate and Joyner (1958) also reported heterosis in kenaf. Estimates of combining ability are useful in determining the breeding value of

kenaf germplasm by suggesting appropriate use in kenaf improvement (Pace *et al.,* 1998). Bamhre *et al.* (1991) reported that kenaf plant height, stem girth, dry stalk weight and length of fiber are predominantly affected by GCA effects. However, Srivastava *et al*. (1978) stated a predominance of non-additive gene action for plant height, days to flowering and base diameter in a full diallel cross. Chen *et al.* (2004) reported that plant height, fresh bark thickness and fiber fineness were controlled by both additive and dominant gene action; stem diameter, dry bark weight per plant, dry stem weight per plant, bark rate, rate of bark/core, fiber weight per plant, retting rate, and fiber strength were mainly controlled by dominant genes.

The GCA:SCA ratio is studied as parameter of the genetic variability in a diallel analysis. It estimates the type of gene action, which controls a particular characteristic (Quick, 1978; Sayed, 1978). When the ratio is high, it means the effect of the additive genes is prevalent. If the ratio is lower, it means the effect of non-additive genes is prevalent in determining a particular character. If GCA variance is higher than SCA variance, the greater is the magnitude of additive genetic effects. Otherwise, the non-additive or dominant genetic variances are prevalent (Baker, 1978). The closer this ratio is to unity the greater the magnitude of additive genetic effects.

2.6.2 Heterosis

Shull (1914) first gave the concept of “heterosis”. Heterosis is defined as the increased vigor, size, yield or resistance to diseases of hybrid, over the parents, due to the crossing between genetically different organisms (Allard, 1960). Jinks (1954) defined heterosis as a deviation from the mean of the parent with the highest yield. As a commercial concept, heterosis is described as the degree of hybrid performance over the best available parent line (Virmani and Edwards, 1983). Crow (1952) indicated that there are two prominent theories of heterosis named the dominance and over dominance hypothesis. Heterosis under the dominance hypotheses is caused by the masking of deleterious recessive alleles in one cultivar by dominant or specific dominant alleles in the second cultivar. Some authors explain the heterosis with these hypotheses: (a) partial dominance of a large amount of loci, (b) over dominance of several loci, (c) several types of epistasis. Sinha and Khanna (1975) reported that, based on parents used, there are two major types of estimates of heterosis: 1) Mid-parent or average heterosis (MPH), which is the increased vigor

of the F1 over the mean of two parents; 2) High-parent or better parent heterosis (HPH), which is the increased vigor of the better parent.

Heterosis is a genetic phenomenon resulting from heterozygosity, but the genetic basis of heterozygosity is still vague. Heterosis results from combined action and interaction of allelic and non-allelic factors and is commonly closely and positively correlated with heterozygosity (Burton, 1968). Flintham *et al.* (1997) explained that the heterozygosity is an essential component of heterosis and it can arise when the over dominance at a single locus is the major cause of heterosis. Heterosis is an important parameter of plant improvement, and efforts will be continued in many plant species. It has been utilized successfully even though its genetic basis has not been determined for the large part (Hallauer, 1999).

A large amount of heterosis has been reported for kenaf hybrids. Dempsey (1963) found the yield of a kenaf F1 generation 14-43% higher than that of the parents. Hybrid kenaf cultivars are grown extensively in China, and increasingly in India (Li, 2000). Qi *et al.* (1992) studied kenaf yield and quality traits, and reported that for dry bark weight per plant, dry stem weight per plant, fiber weight per plant, the F1 generations showed a high heterosis over mid-parents (HMP: 15.7-18.0%) or better parent (HBP: 8.3-13.9%) with the highest heterosis from 35.6 to 69.2%. A higher positive heterosis was also found in the F2 generation. Kenaf F1 heterosis could be retained 1.4-1.7 generations on average. The favorable hybrid could last for 3-4 generations.

2.6.3 Variance components and heritability

Variance components

Quantitative genetics is involved the variation expressed by quantitative traits. The variation is measured and expressed in terms of variance. The given trait's total variance is its phenotypic variance (Vp), or the variance of phenotypic values. It is the sum of environmental variance (V_E) and genetic variance (V_G). $V_P = V_E + V_G$ (Falconer and Mackay, 1996). Environmental variance is a source of error in genetic studies and includes all the variation of non-genetic origin. It reduces the efficiency of the selection procedure by the interaction between genotypes and phenotypes (Lynch and Walsh, 1998). To breeders, the genetic variance is more important, because it

determine the rates at which characters respond to selection. Dudley and Moll (1969) stated: $V_G = V_A + V_D + V_I$. They indicated the total genetic variance (V_G) is composed of additive genetic variance (V_A), dominance genetic variance (V_D) and epistatic genetic variance (V_I). The most important component is V_A, which is the variance of selection values.

Heritability

Heritability determines the degree of resemblance between relatives and it expresses the proportion of the total variance that is attributable to differences of breeding values (Falconer and Mackay, 1996). The term heritability has been further divided into two different concepts, broad sense and narrow sense heritability. The broad sense heritability is defined as the ratio of total genetic variance to phenotypic variance $h^2_b = V_G/V_P$. The narrow sense heritability is the ratio of additive genetic variance to phenotypic variance $h^2_n = V_D/V_P$ (Dudley and Moll, 1969). Narrow sense heritability is more reliable and it is important to breeding programs, because only additive genetic variability is inherited to the next generation (Chaudhary, 1982). Characters with high narrow sense heritability h^2_n values can be selected more quickly with less intensive evaluation than those with low h^2_n values and therefore are useful in making selection progress estimates. Broad sense heritability h^2_b includes non-additive effects and consequently overestimates the response of selection (Dudley and Moll, 1969).

Heritability estimates are useful methods in designing an effective hybrid program. They provide an indication of the expected response to selection in a segregating population (Burton and Devane, 1953). Jones (1986) indicated that heritability determines the degree of resemblance between relatives and is an important parameter for breeders. Johnson *et al.* (1955) stated that heritability, assessed in conjunction with calculating expected genetic gains using h^2_n or h^2_b estimates, are more effective and reliable in predicting the improvement through selection.

Mostofa *et al*. (2002) studied the heritability of kenaf. They reported that high heritability was observed for days to 50% flowering (h^2=0.98) and green weight per plant (h^2=0.44). They suggested the dominant role of additive gene effects in the expression of those two characters.

2.7 Genotype by environment interaction and stability statistics

2.7.1 Concept and importance

Plant breeders have identified three sources of variation in plant characteristics. genotype (G), environment (E) and GXE interaction (Nel *et al*., 1998). The aims of plant breeding are to improve crop production either within a given macro-environment or in a wide range of growing conditions (Nassar and Huehn, 1987; Ceccarelli, 1989). A successful cultivar needs to possess high and stable yield potential over a wide range of environmental conditions (Becker and Leon, 1988). GXE interaction occurs widely in plant breeding programs. It causes cultivars to perform different ranks in different environments and may cause selections from one environment to perform poorly in another. It is often used to refer to fluctuations of yield across the environments and forces plant breeders to check genotypic adaptation (Ramagosa and Fox, 1993; Basford and Cooper, 1998).

Eberhart and Russel (1966) stated that knowledge of GXE interaction could help to reduce the cost of extensive genotype evaluation by eliminating unnecessary testing trails and by fine-tuning breeding programs. GXE interaction is considered quantitative if the ranking of genotypes do not change in different environments (Baker, 1988).

A number of statistical methods are used for estimation of phenotypic stability. The classical parametric stability statistics are ecovalence, environment variance, regression coefficient, and sum of squared deviations from regression (Lin *et al.,* 1986). The authors classified stability into three types:

1) A stable genotype is characterized by a small variance across all environments.
2) Is defined as fitting a linear regression model and having a unity slope.
3) If the residual mean squares from the regression model on the environment index is small (Eberhart and Russel, 1966).

2.7.2 Statistical analysis of GXE interaction

Analysis of variance

In a conventional cultivar evaluation, it is trails in which the yield of genotype (G) is estimated in environment (E) over replicates (R). The classic model to analyze various traits' variation contained in GER observations, is the analysis of variance (Fisher, 1918). After removing the replicate effect when combining the data, the GE observations are partitioned into two sources: (1) additive main effects for genotype and environments; (2) the non-additive effects due to genotype by environment interaction. The analysis of variance of the combined data expresses the observed (Y_{ij}) mean yield of the i^{th} genotype at the j^{th} environment as:

$$Y_{ij} = \mu + G_i + E_j + GE_{ij} + e_{ij.}$$

Where μ is the general mean, G_i, E_j, and GE_{ij} represent the effect of the genotype, environment and genotype by environment interaction respectively, and e_{ij} is the average of random error associated with the r^{th} plot that receives the i^{th} genotype in the j^{th} environment. The non-additive interaction (GE_{ij}) implies that an expected value (Y_{ij}) depends on the level of G and E separately and the particular combination of levels G and E (Crossa, 1990).

Crossa (1990) stated that a useful aspect of analysis of variance is that the variance component related to the different sources of variation, including genotype and GxE interaction, can be determined. Commonly, variance component methodology is important in multi-location trails since errors in determining the performance of a genotype arise largely from GXE interaction. In a breeding program, variance component methodology is used to estimate genetic variability and to measure the heritability and predicted gain of traits under selection.

Shukla's procedure of stability variance

Shukla (1972) defined the stability variance as an unbiased estimate of the variance of genotype i across environments after the removal of environment main effects. The stability variance is based on the residual (GE_{ij}+ e_{ij}) matrix. The stability statistic is measured as follows:

$$\sigma_i^2 = \frac{1}{(G-1)(G-2)(E-1)}[G(G-1)\sum_j(Y_{ij} - \overline{Y_{i\cdot}} - \overline{Y}_{\cdot j} + \overline{Y}_{\cdot\cdot})^2 - \sum_i\sum_j(Y_{ij} - \overline{Y_{i\cdot}} - \overline{Y}_{\cdot j} + \overline{Y}_{\cdot\cdot})^2]$$

A genotype is called stable if its stability variance (σ^2_i) is equal to environmental variance (σ^2_o), which means that $\sigma^2_i = 0$. A relatively large value of σ_i^2 will thus indicate greater instability of genotype *i*. As the stability variance is the difference between two sums of squares, it can be negative, but negative estimates of variances are not uncommon in variance components problems. Negative estimates of σ^2_i may be taken as equal to zero as usual.

Lin and Binns' cultivar superiority measure (P_i)

Lin and Binns (1988) suggested the use of the cultivar performance measure (P_i) and stated P_i of genotype I as the mean squares of distance between genotype i and the genotype with the maximum response. The stability statistic is measured as follows:

$$P_i = [n(Y_i - M_{\cdot\cdot})^2 + (Y_{ij} - Y_{i\cdot} + M_j + M_{\cdot\cdot})^2]/2n$$

Where Y_{ij} is the average response of genotype *i* in environment *j*, Y is the mean deviation of genotype *i*, M_j is the genotype with maximum response among all genotypes at environment *j*, and n is the number of locations

Wricke's ecovalence (Wi)

Wricke (1962) defined the concept of ecovalence as the contribution of each genotype to the GXE interaction sum of squares. When the ecovalence value is higher, the genotype's contribution to the total GXE sum of the squares is also greater. Ecovalence is simple to compute and is expressed as:

$$Wi = \Sigma_j [Y_{ij} - Yi - Y_j + Y \ldots.]^2$$

Eberhart and Russel's joint regression analysis

Eberhart and Russel (1966) proposed joining linear regression of the mean of the genotype on the environmental mean as an independent variable. In this model, it defines stability parameters that may be used to estimate the performance of a genotype over different environments.

The first measure is the slope *bi* from the regression of the yield of genotype *i* on an environmental index (Finlay and Wilkinson, 1963). Where *b* is equal to 1, it indicates that a cultivar reacts to a change in environment in the same way as the group mean.

Additive main effects and multiplicative interaction method (AMMI)

The additive main effects and multiplicative interaction method (AMMI) method integrates analysis of variance and principal component analysis into an unified approach (Gauch, 1988) and is especially useful in estimating multi-location trials (Gauch and Zobel, 1988). AMMI combines analysis of variance and principal component analysis into one model with additive and multiplicative parameters. The results can be graphed in a very informative biplot that shows both main and interaction effects for genotypes and environments (Kang, 1996).

The AMMI analysis gives more precise estimates of genotype yields within locations than means across replicates in different trials (Crossa *et al*.,1991). The main important feature of AMMI analysis is its graphical (biplot) representation. This displays main effect means on the abscissa and scores for the first axis (IPCA1 values) as ordinate of both genotypes and environments simultaneously (Crossa, 1990; Gauch and Zobel *et al.,* 1988). Genotypes or environments with large PCA (positive or negative) scores have large interaction, whereas a PCA score near zero has small interaction effects (Zobel *et al*., 1988; Crossa *et al*., 1991). Accordingly, a large genotypic IPCA1 value reflects more specific adaptation to environments with IPCA1 values of the same sign. On the contrary, genotypes with IPCA1 values close to zero show wider adaptation to the tested environments. Thus, IPCA scores of a genotype in the AMMI analysis are the key to interpret the pattern of genotype responses across environments (Zobel *et al*., 1988; Gauch and Zobel, 1988; Crossa *et al*., 1991).

Chapter 3

Heterosis and combining ability in a full diallel cross of kenaf (*Hibiscus cannabinus* L.)

3.1 Introduction

A large number of kenaf varieties have been developed in recent decades (Institute of Bast Fiber Crops, 1985; Bitzer*,* 2000), but there is interest to pursue further improvement of both productivity and fiber quality through breeding activities because genetic gains can be exploited without a concomitant increase in the cost of crop management (Pace *et al.*, 1998).

Heterosis in kenaf has been studied and F1's have been commercially utilized in some countries (Pate and Joyner, 1958; Nelson and Wilson, 1965; Li, 2000). Hybrids are the first generation offspring of a cross between parents with contrasting genotypes (Allard, 1960). The release of superior hybrids could improve the productivity of kenaf. Many breeders are devoting themselves to kenaf hybrid breeding programs.

Identification and selection of parental lines are required to be used in any hybridization program to produce potentially rewarding germplasm with an assembly of fixable gene effects more or less in a homozygous line (Mohammad, 2003). Danish animal breeder, Schmidt, first introduced the diallel-crossing concept in 1919 (Pirchner, 1979). It has probably attracted more attention and has been the subject to more theoretical and practical application than other mating designs (Wright, 1985).

In diallel analysis, general combining ability is regarded as additive gene action and specific combining ability reflects non-additive gene actions (Sprague and Tatum, 1942). Estimates of additive and non-additive gene action are important in early stages of breeding procedures (Dudley and Moll, 1969). Selection would be successful during the early generations when additive gene action is predominant. Otherwise, the selection would be at later generations when these effects are fixed in the homozygous line. A number of studies on combining ability of kenaf fiber yield and quality and agronomic traits were reported (Patil and Thombre, 1980; Qi *et al.,* 1992; Pace *et al.,* 1998).

In kenaf, several traits are important for the yield and fiber quality. Thus different breeding methods may be necessary for improvement of traits under consideration. Pace *et al.* (1998) reported that plant height, basal diameter, dry bark weight and ratio between dry bark weight/woody core weight are major components of fiber yield and quality.

The aim of this study was:

1) To estimate the combining ability, additive and non-additive gene effects of the selected cultivars.
2) To determine the expression of heterosis for the different characteristics.
3) To measure the heritability of the traits.

3.2 Materials and methods

3.2.1 Plant materials

A total of six kenaf cultivars were used in this study. Seeds were obtained from The Sustainable Project Development Group of the UK and ARC Institute of Industrial Crops. Table 3.1 shows the detail of six cultivars .

Table 3.1 Six kenaf cultivars used for the full diallel cross

Entry	Name	Origin
1	Cuba108	Spain
2	Dowling	USA/Mexico
3	Endora	Spain
4	Everglades 41	Spain
5	Gregg	USA/Mexico
6	Tainung	USA/Mexico

3.2.2 Generation of F1 seed from diallel cross

The seed of parental cultivars was germinated in petri dishes in February 2004. After three days, seedlings were transplanted into 3l pots in a greenhouse at the University

of the Free State. There were 10 pots for each cultivar in one block, three blocks. Three seeds were planted in each pot and thinned out to one plant per pot at the beginning of March.

The temperature of the greenhouse was maintained at 19 ^{o}C (night) to 30 ^{o}C (day). Fertilizer was given every two weeks to each pot. Aphids and red spider were controlled as necessary. Plants were watered regularly.

According to the formula designed by Griffing (1956) method 1, 30 crosses were made from the six parents (P). Number of crosses = P (P-1). The total entries were therefore 36 (parents, crosses and reciprocals). The ready-to-open flower buds were hand emasculated and pollinated to produce all possible combinations of F1 hybrids with reciprocals. Flowers were emasculated late in the afternoon. The emasculated flowers were covered with small paper caps to prevent pollination from other flowers. Pollination was done early the next morning. Pollen was used from freshly dehisced anthers. As Li (2000) reported, kenaf pollen was non-active after 12h00 pm. The best pollination time is between 9h00 -11h00 in the morning. So, all pollinations were done before 11h00 in the morning. Three to five days after pollination, paper caps were taken off.

The F1 pods were harvested at full physiological maturity after 60-80 days, when the color of seeds darkened. Each individual cross was threshed by hand (Table 3.2).

Table 3.2 Full diallel cross of six kenaf parent lines

Entry	Female line	Male line	F1 Hybrids	Number of seeds
1	Cuba 108(1)	Dowling(2)	1 x 2	200
2	Cuba 108(1)	Endora(3)	1 X 3	220
3	Cuba 108(1)	Everglades 41(4)	1 X 4	220
4	Cuba 108(1)	Gregg(5)	1 X 5	200
5	Cuba 108 (1)	Tainung(6)	1 X 6	190
6	Dowling(2)	Cuba108(1)	2 X 1	170
7	Dowling(2)	Endora(3)	2 X 3	77
8	Dowling(2)	Everglades 41(4)	2 X 4	100
9	Dowling(2)	Gregg(5)	2 X 5	170
10	Dowling(2)	Tainung(6)	2 X 6	48
11	Endora(3)	Cuba 108(1)	3 X 1	120
12	Endora(3)	Dowling(2)	3 X 2	110
13	Endora(3)	Everglades 41(4)	3 X 4	120
14	Endora(3)	Gregg(5)	3 X 5	180
15	Endora(3)	Tainung(6)	3 X 6	110
16	Everglades 41(4)	Cuba 108(1)	4 X 1	85
17	Everglades 41(4)	Dowling(2)	4 X 2	60
18	Everglades 41(4)	Endora(3)	4 X 3	160
19	Everglades 41(4)	Gregg(5)	4 X 5	110
20	Everglades 41(4)	Tainung(6)	4 X 6	90
21	Gregg(5)	Cuba 108(1)	5 X 1	200
22	Gregg(5)	Dowling(2)	5 X 2	230
23	Gregg(5)	Endora(3)	5 X 3	210
24	Gregg(5)	Everglades 41(4)	5 X 4	200
25	Gregg(5)	Tainung(6)	5 X 6	160
26	Tainung(6)	Cuba 108(1)	6 X 1	110
27	Tainung(6)	Dowling(2)	6 X 2	150
28	Tainung(6)	Endora(3)	6 X 3	210
29	Tainung(6)	Everglades 41(4)	6 X 4	80
30	Tainung(6)	Gregg(5)	6 X 5	150

3.2.3 Trial design

Thirty six entries, including six parental genotypes and 30 progenies produced in full diallel cross among the six genotypes were used in this study. The seeds were sown at Tempe farm (15 km from University of the Free State) on 23 October 2004. Due to poor seed set, only one trial could be planted. The trial was planted as a randomized complete block design with two replications.

The previous crop was wheat. The land was ploughed and disked before N:P:K fertilizer was spread over the area. Seventy two plots were planted with 2.5 m rows, each plot had two rows. Seeds were sown at 25 cm inter-row spacing and 50 cm path was left between plots. Intra-plant spacing was 10 cm.

Sprinkler irrigation was provided weekly during the early stage of seedling growth. No pesticide and herbicide were used during the growing season.

Plots were harvested by hand on the 15th to18th May 2005.

3.2.4 Characteristics measured

According to the SPDG (Sustainable Projects Development Group of the UK) suggestions and the literature (Pace *et al.,* 1998; Shamsuddin *et al.,* 2001; Chen *et al.,* 2004) the following traits were measured on 10 plants from each plot.

Fresh plant mass: (FPM) The weight of whole fresh plants.

Defoliated plant mass: (DPM) The weight of whole fresh plants without leaves.

Plant height: (PH) The height of the whole plant.

Basal diameter: (BD) The diameter of the base of plant, just above ground.

Middle diameter: (MD) The diameter of the middle of plant.

One meter stalk mass: (MSM) The weight of one meter of fresh stalk taken from the middle of the plant.

Dry one meter stalk mass: (DMSM) The weight of one meter stalk that was put into an oven to dry for 5 days at 60 ^{o}C.

Dry mass percentage: (DS%) From DMSM, calculated "dry stalk mass/one meter stalk mass x 100%".

Bast mass: (BM) The weight of bast in one meter length of above ground dried stalk.

Core Mass: (CM) The weight of core in one meter length of above ground dried stalk.

Bast mass/ core mass: (BM/CM) The ratio of bast weight: core weight.

Qi *et al.* (1992) stated that the ratio of bast weight: core weight (BM/CM) is the one of the three most important parameter of kenaf. It affects the paper quality and quantity directly. The industry needs a bigger ratio to increase paper production.

3.2.5 Statistical analysis

A range of statistical analysis was done with Agrobase (2000) and Microsoft EXCELL (software packages).

Combining ability

Griffing (1956) designed two main models and four methods for the analysis of diallel data. In this study, analysis of the combining ability for each experiment was done following Griffing's Method 1, where parents, F1's and reciprocals are included. The data was analyzed with Agrobase (2000) using a fixed model. If the fixed effects model is used, the sampling error becomes the effective residual for testing combining ability mean squares and estimating variance components and standard errors.

GCA : SCA ratio

The GCA:SCA ratio was estimated to study the performance of the effects and to measure the relative importance of additive gene or non-additive gene effects. This

parameter indicates whether a character is mainly determined by additive or non-additive gene action (Singh and Chaudhary, 1979).

Heritability

Heritability is the portion of the total phenotype variance among individuals that is attributable to genetic variance (Wricke and Weber, 1986; Fehr, 1987). Falconer and Mackay (1996) define the concepts of broad sense and narrow sense heritability as follow:

Broad sense heritability is calculated from the formula:

$$h_b^2 = \sigma_G^2 / \sigma_P^2$$

Where: σ_G^2 is total genotypic variance; σ_P^2 is the total phenotypic variance

Narrow sense heritability was calculated from the formula:

$$h_n^2 = \sigma_A^2 / \sigma_P^2$$

$$\sigma_A^2 = 2\sigma^2_{GCA} \qquad \sigma^2_{GCA} = (M_g - M_s)/(P-2)$$

Where:

σ_A^2	additive variance
σ^2_{GCA}	general combining ability variance
M_g	general combining ability mean squares
M_s	specific combining ability mean squares
P	number of parents

Variance components were obtained from the diallel analysis following the fixed model of the Griffing (1956) analysis, method 1.

Heterosis

Two types of the heterosis were analyzed based on the mean values of the genotypes in this study; mid-parent heterosis (MPH) and high parent heterosis (HPH).

The MPH is calculated from the formula (Falconer and Mackay, 1996):

$$H_{F1} = (F1 - MP)/MP \times 100\%$$

Where: H_{F1} is the heterosis for F1 cross
F1 is the mean value of F1 cross
MP is the mean mid-parent value

And HPH is calculated from the formula:

$$H_{F1} = (F1 - HP)/HP \times 100\%$$

Where: H_{F1} is the heterosis for F1 cross
F1 is the mean value of F1 cross
HP is the mean high parent value

3.3 Results and discussion

3.3.1 Analysis of variance

Analysis of variance was done on all data obtained from the parents and F1 hybrids for 11 different characteristics. From this analysis one LSD was calculated which was used in the figures to compare the entries.

The mean squares (MS) for genotype were significant for FPM, DPM, PH, BD,and MD ($p<0.01$) (Table 3.3). It shows that there were significant differences between entries for each of these characteristics. Only two characteristics, DPM and DS% were significantly different ($p<0.05$) for the replication MS. It means that environmental differences between blocks existed in those two characteristics.

Table 3.3 Mean squares for GCA and SCA for various characteristics of kenaf

Source	df	FPM	DPM	PH	BD	MD	DS%	BM	CM	BM/CM
Replication	1	1672.540	31543.184*	0.125	0.180	0.113	57.423*	60.683	176.407	41.102
Genotype	35	115951485**	53656.037**	0.288**	0.352**	0.117**	10.287	40.344	358.361	25.355
GCA	5	25379.520*	12876.027*	0.144*	0.125*	0.054*	9.305	10.563	102.693	21.892
SCA	15	94303.288**	42989.730**	0.211**	0.254**	0.080**	5.167	25.702*	244.100*	7.896
Reciprocals	15	16767.392	7554.138	0.063	0.050	0.036	9.727	24.769	232.747	22.773

*** P<0.01,* P<0.05*

FPM= Fresh plant mass; DPM= Defoliated plant mass; PH= Plant height; BD= Basal diameter; MD= Middle diameter; DS%= Dry one meter_stalk mass Dry mass percentage; BM= Bast mass; CM= Core mass; BM/CM= Bast mass/ core mass

3.3.1.1 Fresh plant mass (FPM)

For fresh plant mass the parent with the highest ranking was Tainung(6), followed by Gregg(5) and Cuba108(1) (Figure 3.1). Tainung(6) differed significantly from other parents (Figure 3.1). The parent with the lowest ranking was Dowling(2). In the F1 hybrids, Tainung(6)x Dowling(2) was the best performing hybrid followed by Tainung(6) x Dowling(2), Endora(3) x Gregg (5), Endora(3) x Dowling(2), Gregg (5) x Endora(3), Gregg (5) x Dowling(2), Cuba108(1) x Gregg (5), and Endora(3) x Tainung(6). These crosses were significantly different from all the other crosses. The lowest ranking F1 hybrid was Cuba108(1) x Dowling(2), which also differed significantly from all the other crosses.

3.3.1.2 Defoliated plant mass (DPM)

For DPM averages the parent, Tainung(6) was significantly higher than all the parents except Cuba108(1) (Figure 3.2). Among the parental lines, Tainung(6) was followed by Cuba108(1) and Gregg (5). The F1 hybrid with the highest DPM was Tainung(6) x Dowling(2). Endora(3) x Dowling(2) and Endora(3) x Gregg (5) also showed higher DPM values following Tainung(6) x Dowling(2). Dowling(2) had the lowest DPM ranking of all the entries.

3.3.1.3 Plant height (PH)

For plant height (PH) the parental line Tainung(6) had the highest PH of the parents, followed by Gregg (5), Cuba108(1) (Figure 3.3). Of the F1 hybrid, Gregg (5) x Dowling(2) ranked the highest among the crosses, followed by Endora(3) x Gregg (5) and Gregg (5) x Everglades 41(4). The lowest parental line was Everglades 41(4). It differed significantly from all the F1 hybrids except Everglades 41(4) x Dowling(2).

3.3.1.4 Basal diameter (BD)

For the basal diameter (BD) the parent which had highest BD value was Tainung(6), followed by Cuba108(1) and Gregg (5) (Figure 3.4). Tainung(6) differed significantly from the other parents except Cuba108(1). The lowest ranking parent was Dowling(2). The 10 crosses' BD value was significantly higher than all the parental

lines. The highest cross was Tainung(6) x Dowling(2). The worst performing hybrid was Cuba108(1) x Dowling(2), followed by Dowling(2) x Everglades 41(4).

3.3.1.5 Middle diameter (MD)

From Figure 3.5, it was shown that Tainung(6) was the highest ranking parent for MD. It differed significantly from all the parents except Gregg (5), which had the smallest MD but it was not significantly different from other parents. It was Tainung(6) x Dowling(2) that had the highest MD value of all crosses and entries, followed by Endora(3) x Dowling(2) and Gregg(5) x Endora(3). Cuba108(1) x Dowling(2) was the cross with the lowest rank, it differed significantly from most of the other crosses.

3.3.1.6 Dry mass percentage (DS%)

Gregg(5) was the highest ranking parent for the DS%, followed by Tainung(6). The lowest ranking parent was Endora(3) (Figure 3.6). It differed significantly from Gregg(5). Gregg(5) x Endora(3) had the highest DS% value of all hybrids, it differed significantly from all the parents. It was Gregg(5) x Cuba108(1), which had the lowest ranking of the F1 hybrids.

3.3.1.7 Bast mass (BM)

For bast mass (BM) (Figure 3.7) the highest ranking parents was Tainung(6), followed by Cuba108(1) and Gregg(5). But those parents did not differ significantly from one another. Gregg(5) x Dowling(2) was the best cross for DM. It had a significantly higher value than other crosses and parents except Endora(3) x Gregg(5), Tainung(6) x Cuba108(1), and Gregg(5) x Everglades 41(4). The lowest value was measured for Cuba108(1) x Dowling(2).

3.3.1.8 Core mass (CM)

The CM of parent Tainung(6) was the highest, followed by Everglades 41(4) and Cuba108(1) (Figure 3.8). Their values were not significantly higher than other parents. The lowest ranking parental line was Dowling(2). Gregg(5) x Dowling (2) and Endora(3) x Gregg(5) were highest ranking among all of the entries. They differed

significantly from most of the other crosses. The worst performing hybrid was Cuba108(1) x Dowling(2).

3.3.1.9 Bast mass: core mass (BM/CM)

The highest ranking parent for average bast mass: core mass (BM/CM) was Cuba108(1), which was significantly higher than other parents except Dowling(2) (Figure 3.9). The lowest ranking parent was Everglades 41(4). Endora(3) x Cuba108(1) and Tainung(6) x Cuba108(1) had the highest rankings, but was close to the best parent Cuba108(1). The F1 hybrid with the lowest ranking was Endora(3) x Gregg(5), its value was lower than all of the parent lines.

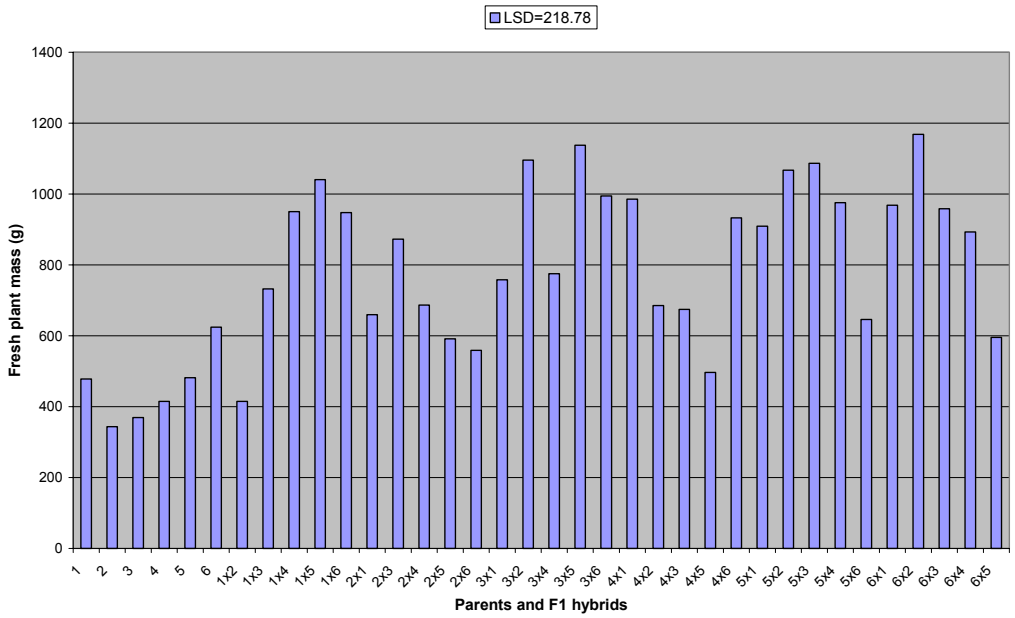

Figure 3.1 Fresh plant mass of the parents and F1 hybrids

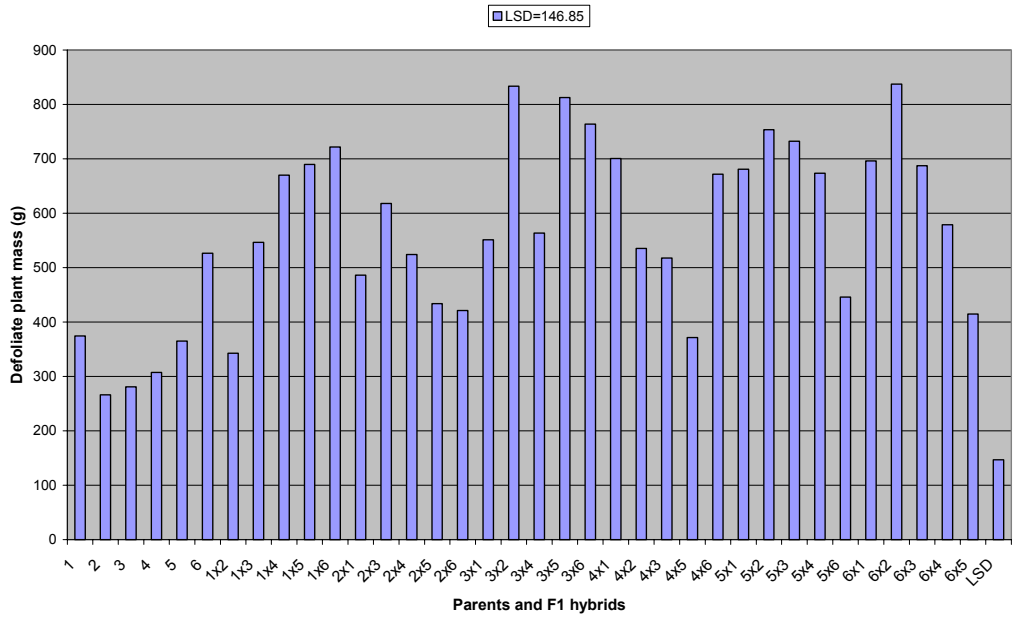

Figure 3.2 Defoliated plant mass of parents and F1 hybrids (LSD p<0.05)

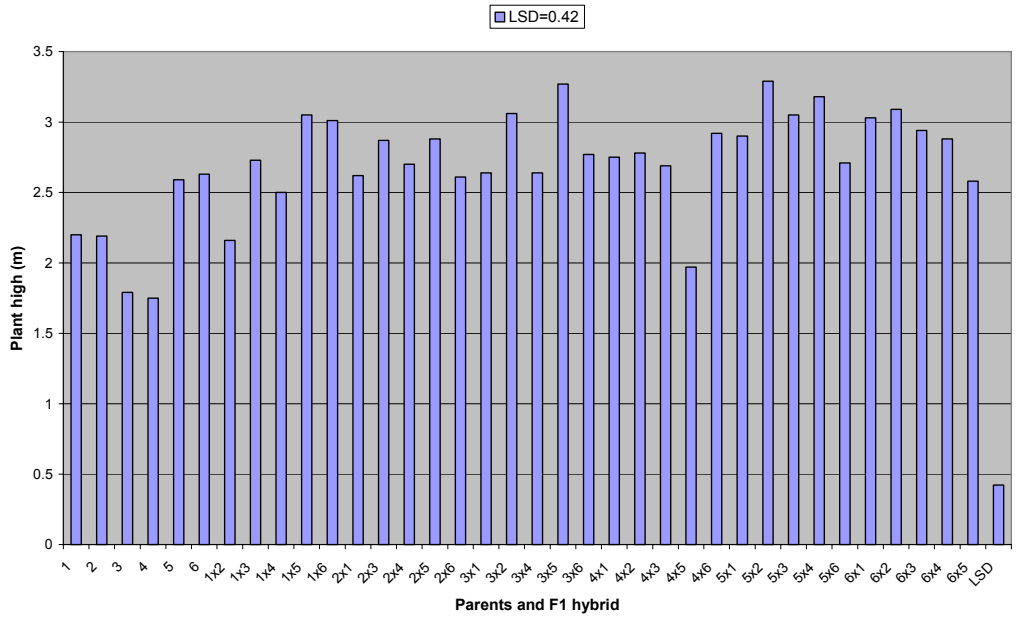

Figure 3.3 Plant height of the parents and F1 hybrids (LSD p<0.05)

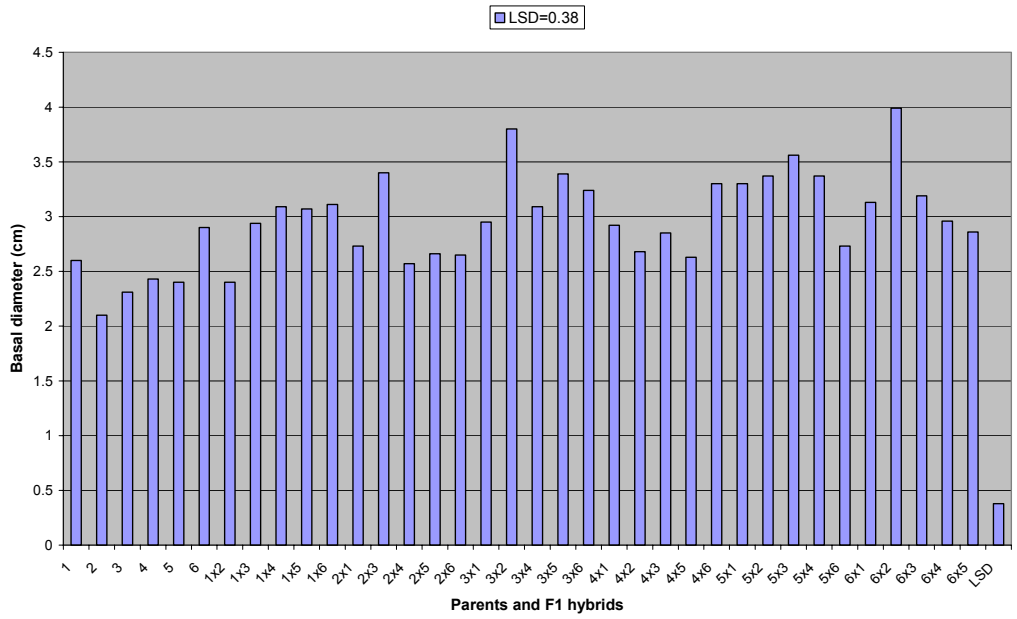

Figure 3.4 Basal diameter of the parents and F1 hybrids (LSD p<0.05)

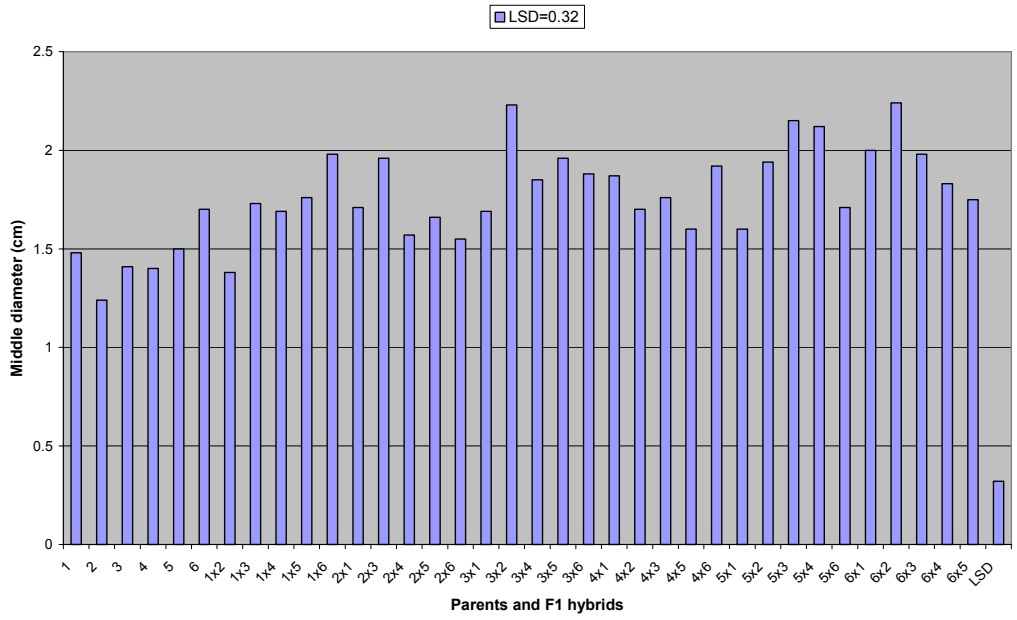

Figure 3.5 Middle diameter of the parents and F1 hybrids (LSD p<0.05)

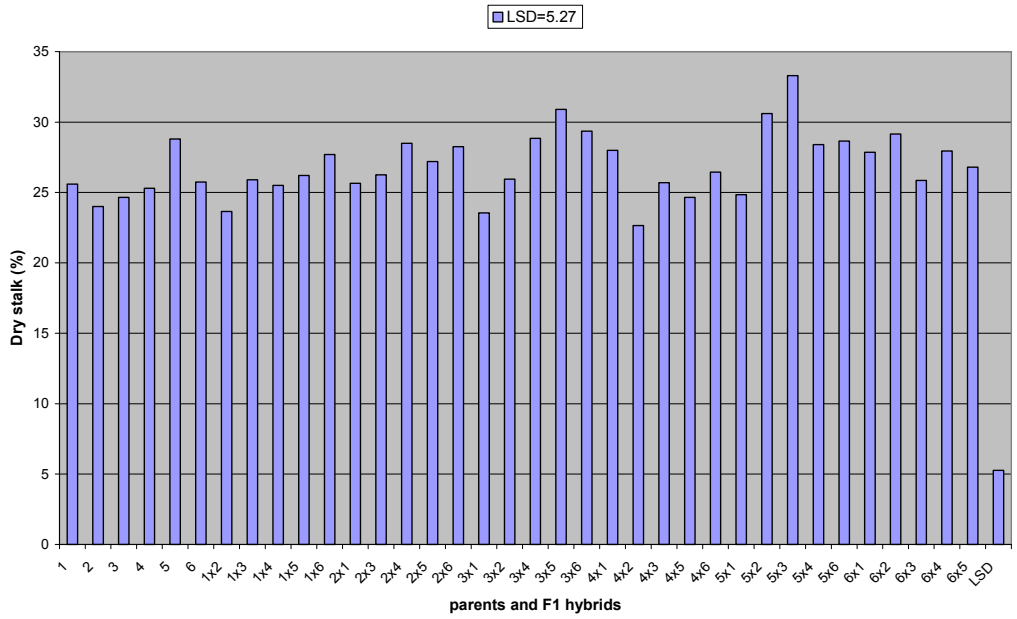

Figure 3.6 Dry mass percentage (DS%) of parents and F1 hybrids (LSD p<0.05)

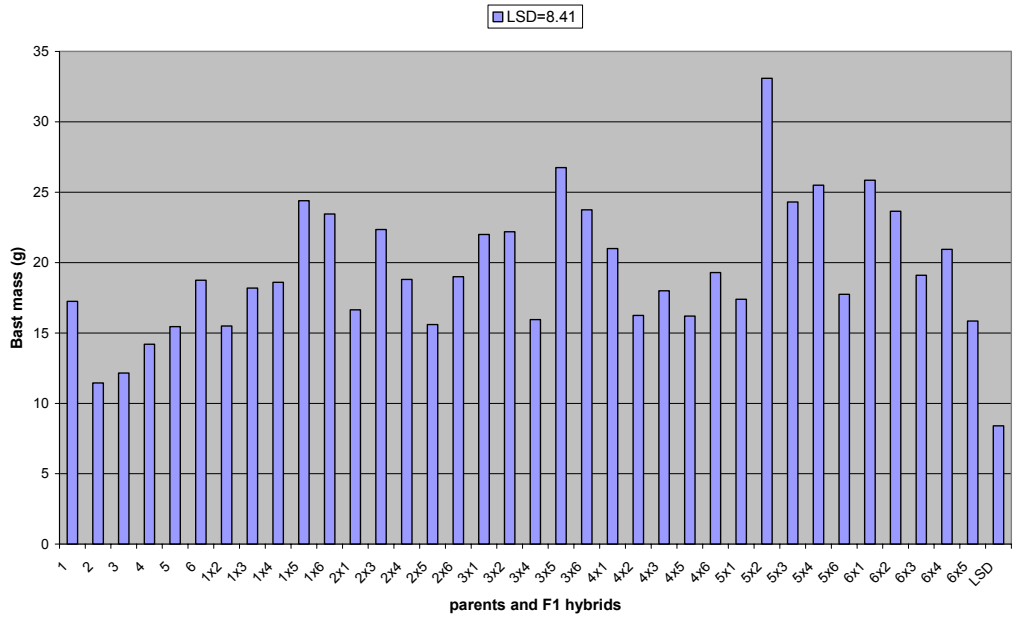

Figure 3.7 Bast mass of parents and F1 hybrids (LSD p<0.05)

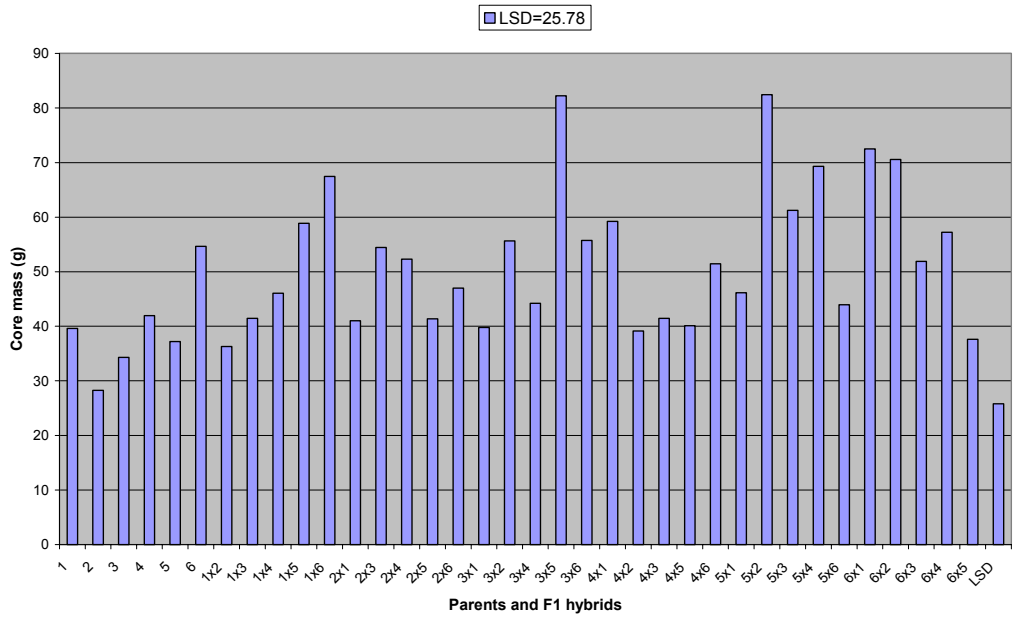

Figure 3.8 Core mass of the parents and F1 hybrids (LSD p<0.05)

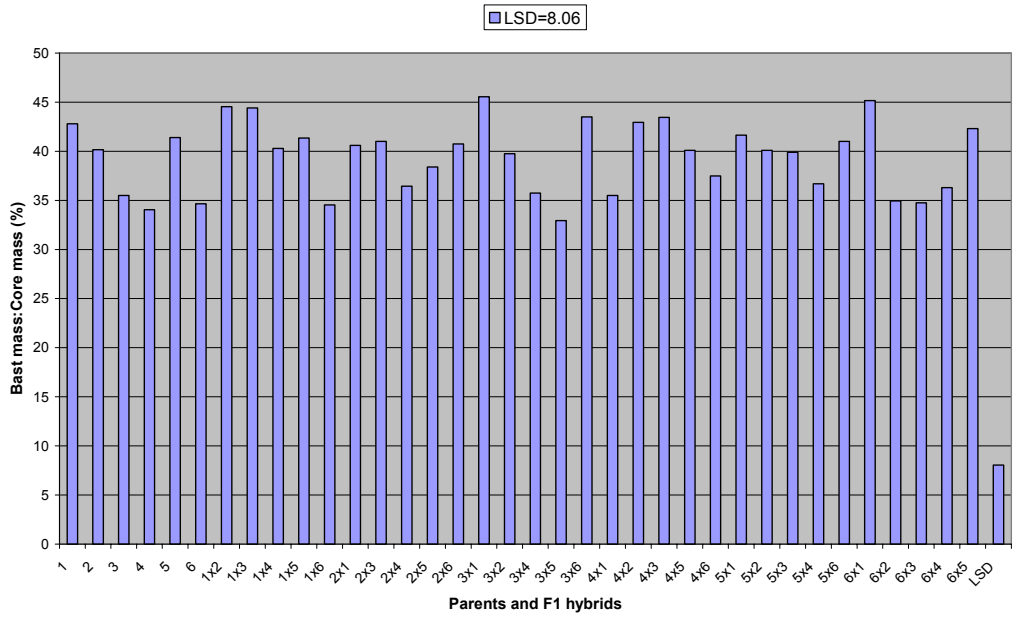

Figure 3.9 Bast mass: core mass of the parents and F1 hybrids (LSD p<0.05)

**1=Cuba108; 2=Dowling; 3=Endora; 4=Everglades 41; 5=Gregg; 6=Tainung*

Table 3.4 Averages of parents and progeny for measured characteristics

Genotype	FPM	DPM	PH	BD	MD	DS%	BM	CM	BM/CM
1	478.22	374.44	2.20	2.60	1.48	25.60	17.25	39.60	42.80
2	343.06	266.21	2.19	2.10	1.24	24.00	11.45	28.25	40.15
3	369.03	280.91	1.79	2.31	1.41	24.65	12.15	34.30	35.50
4	414.82	307.20	1.75	2.43	1.40	25.30	14.20	41.95	34.05
5	481.23	365.00	2.59	2.40	1.50	28.80	15.45	37.20	41.40
6	624.43	526.37	2.63	2.90	1.70	25.75	18.75	54.65	34.65
1x2	415.21	342.66	2.16	2.40	1.38	23.65	15.50	36.30	44.55
1x3	732.32	546.68	2.73	2.94	1.73	25.90	18.20	41.45	44.40
1x4	950.40	669.89	2.50	3.09	1.69	25.50	18.60	46.05	40.30
1x5	1040.86	689.54	3.05	3.07	1.76	26.20	24.40	58.85	41.35
1x6	947.34	721.51	3.01	3.11	1.98	27.70	23.45	67.45	34.55
2x1	659.42	486.12	2.62	2.73	1.71	25.65	16.65	41.00	40.60
2x3	873.05	617.88	2.87	3.40	1.96	26.25	22.35	54.45	41.00
2x4	686.75	524.01	2.70	2.57	1.57	28.50	18.80	52.30	36.45
2x5	591.04	433.84	2.88	2.66	1.66	27.20	15.60	41.35	38.40
2x6	558.93	421.16	2.61	2.65	1.55	28.25	19.00	47.00	40.75
3x1	757.76	551.23	2.64	2.95	1.69	23.55	22.00	39.80	45.55
3x2	1095.54	833.57	3.06	3.80	2.23	25.95	22.20	55.65	39.75
3x4	775.14	563.63	2.64	3.09	1.85	28.85	15.95	44.20	35.75
3x5	1137.39	812.54	3.27	3.39	1.96	30.90	26.75	82.25	32.95
3x6	994.51	763.81	2.77	3.24	1.88	29.35	23.75	55.75	43.50
4x1	985.50	700.61	2.75	2.92	1.87	28.00	21.00	59.20	35.50
4x2	684.89	535.41	2.78	2.68	1.70	22.65	16.25	39.15	42.95
4x3	674.40	517.69	2.69	2.85	1.76	25.70	18.00	41.45	43.45
4x5	496.57	371.60	1.97	2.63	1.60	24.65	16.20	40.10	40.10
4x6	932.41	671.71	2.92	3.30	1.92	26.45	19.30	51.45	37.50
5x1	909.40	680.75	2.90	3.30	1.60	24.85	17.40	46.15	41.65
5x2	1067.53	753.67	3.29	3.37	1.94	30.60	33.10	82.45	40.10
5x3	1086.82	732.19	3.05	3.56	2.15	33.30	24.30	61.25	39.90
5x4	976.09	673.61	3.18	3.37	2.12	28.40	25.50	69.30	36.70
5x6	645.92	445.88	2.71	2.73	1.71	28.65	17.75	43.95	41.00
6x1	968.48	696.23	3.03	3.13	2.00	27.85	25.85	72.50	45.15
6x2	1168.50	837.18	3.09	3.99	2.24	29.15	23.65	70.55	34.95
6x3	958.32	687.31	2.94	3.19	1.98	25.85	19.10	51.90	34.75
6x4	893.09	578.89	2.88	2.96	1.83	27.95	20.95	57.25	36.30
6x5	595.50	414.56	2.58	2.86	1.75	26.80	15.85	37.60	42.30
Mean	776.94	566.54	2.70	2.96	1.76	26.90	19.63	50.67	39.46
LSD (0.05)	218.78	146.85	0.42	0.38	0.32	5.27	8.41	25.78	8.06
C.V.%	16.67	15.34	9.25	7.57	10.79	11.59	25.35	30.11	12.90

1=Cuba108; 2=Dowling; 3=Endora; 4=Everglades 41; 5=Gregg; 6=Tainung

3.3.1.10 Discussion

The parent lines and F1 hybrids showed significant differences for most of the characteristics measured. It will be possible to improve these characteristics in a kenaf breeding program by selecting within segregating populations. Of the six parental lines, Tainung(6) in nine characteristics measured (FPM, DPM, PH, BD, MD, MSM, DMSM, BM, CM,) had the top value among the parent lines. Parent Dowling(2), in nine characteristics measured, had the lowest values. For most of the characteristics, hybrids in general had higher values than parent lines. It indicated that heterosis was observed in those characteristics.

Among all of the F1 hybrids, the best crosses were Tainung(6)xDowling(2), Gregg (5)xDowling(2), and Endora(3)xGregg (5). Tainung(6)xDowling(2) ranked the highest in FPM, DPM, BD, MD; Gregg (5)xDowling(2) was highest ranked for PH, DMSM, BM, CM. It indicated that if the yield was the most important selection criteria, the hybrid Tainung(6)xDowling(2) will be the best in a breeding program; otherwise, if the fiber is important in the breeding program, the Gregg (5)xDowling(2) cross will be the best choice.

3.3.2 Combining ability analysis

3.3.2.1 Analysis of variance of GCA and SCA

Dudley and Moll (1969) stated that estimates of relative importance of additive and non-additive gene actions were important to determine the type of breeding method and it would improve the performance of the traits effectively. In this study, the mean squares of GCA and SCA effects were calculated (Table 3.4).

The mean squares of GCA were significant for FPM, DPM, PH, BD, and MD, of which are characteristics that determine yield. The means squares of GCA were not significant for the other characteristics. The mean squares of SCA were significant for all of the characters except DS% and BM/CM.

This indicated that both additive and dominance genetic variances were important in the measured characteristics.

3.3.2.2 General and specific combining ability effects

It is an important indicator of the potential of parental lines for generating superior breeding populations. A small or negative combining ability effect indicates a poor ability to transfer its genetic superiority to hybrids (Cruz and Regazzi, 1994). The largest positive values have the largest effects. On the other hand, the largest negative values have the smallest effects (Tenkouano *et al.,* 1998). In Table 3.5 and Table 3.7, the GCA and SCA values were listed.

In this study, the GCA:SCA ratio for each trait is listed in Table 3.6. A high ratio means that additive gene action is predominant.

Table 3.5 GCA effects for measured characteristics in kenaf

Parent	FPM	DPM	PH	BD	MD	MSM	DMSM	DS%	BM	CM	BM/CM
1	-0.01	2.97	-0.058	-0.059	-0.067	6.69	-1.17	-1.06	0.17	-1.67	2.13
2	-69.69	-40.05	-0.002	-0.093	-0.061	-17.34	-3.57	-0.58	-0.80	-2.61	0.52
3	41.67	32.49	-0.020	0.123	0.070	0.78	-0.99	0.18	0.11	-0.94	-0.13
4	-36.53	-31.42	-0.164	-0.104	-0.038	-8.98	-3.52	-0.46	-1.38	-1.97	-0.17
5	15.52	-5.03	0.132	0.017	0.007	0.04	3.32	1.36	1.02	2.47	0.31
6	49.05	41.04	0.110	0.117	0.089	18.81	5.94	0.55	0.88	4.72	-1.13
LSD (0.01)	20.57	16.86	0.904	0.856	0.788	14.13	8.141	3.19	4.03	7.06	3.95

Table 3.6 GCA:SCA mean square ratio for measured characteristics in kenaf

Characters	FPM	DPM	PH	BD	MD	MSM	DMSM	DS%	BM	CM	BM/CM
GCA:SCA	0.27	0.30	0.68	0.49	0.68	0.48	0.41	1.80	0.41	0.42	2.77

Table 3.7 SCA effects for measured characteristics in kenaf

Cross	FPM	DPM	PH	BD	MD	MSM	DMSM	DS%	BM	CM	B/C
1x2	-169.9	-115.1	-0.26	-0.25	-0.09	-27.72	-10.99	-0.61	-2.93	-7.74	0.46
1x3	-73.6	-53.0	0.05	-0.08	-0.06	-20.04	-7.57	-1.29	0.19	-7.43	3.51
1x4	227.6	147.2	0.14	0.21	0.12	13.93	6.66	1.37	1.39	5.60	-1.99
1x5	182.7	120.7	0.20	0.27	-0.02	21.07	0.79	-1.68	0.09	1.03	-0.41
1x6	131.9	98.3	0.26	0.10	0.20	63.66	22.39	1.38	3.97	16.26	-0.62
2x1	-122.1	-71.7	-0.23	-0.16	-0.17	-4.85	-2.93	-1.00	-0.58	-2.35	1.98
2x3	235.4	166.7	0.28	0.60	0.32	55.59	11.43	-0.40	3.33	7.93	0.52
2x4	15.1	34.6	0.20	-0.14	-0.03	14.83	-0.12	-0.29	0.08	-0.36	1.42
2x5	106.5	72.3	0.25	0.13	0.09	-1.64	16.04	1.22	4.50	11.37	-1.04
2x6	107.4	61.6	0.04	0.33	0.11	17.37	7.27	1.81	1.61	5.99	-1.01
3x1	-12.7	-2.3	0.05	-0.01	0.02	-11.50	-1.08	1.18	-1.90	0.83	-0.58
3x2	-111.2	-107.8	-0.10	-0.20	-0.14	-4.45	-0.53	0.15	0.08	-0.60	0.63
3x4	-57.3	-26.9	0.14	-0.01	0.01	-29.79	-6.15	0.66	-1.38	-4.93	1.97
3x5	278.0	178.4	0.34	0.37	0.22	73.48	24.48	3.66	4.77	19.55	-3.22
3x6	108.8	85.5	0.06	0.01	0.01	-8.22	-0.16	-0.04	0.80	-0.63	0.92
4x1	-17.6	-15.4	-0.13	0.08	-0.09	-16.80	-7.78	-1.25	-1.20	-6.58	2.40
4x2	0.9	-5.7	-0.04	-0.06	-0.07	3.18	7.85	2.93	1.28	6.58	-3.25
4x3	50.4	23.0	-0.03	0.12	0.04	-11.48	0.35	1.58	-1.03	1.38	-3.85
4x5	-19.6	-7.5	-0.10	0.12	0.13	31.25	5.29	-1.28	1.59	3.53	0.34
4x6	123.3	49.1	0.24	0.15	0.06	6.22	1.59	0.20	1.00	0.93	0.27
5x1	65.7	4.4	0.08	-0.12	0.08	31.48	9.85	0.68	3.50	6.35	-0.15
5x2	-238.2	-159.9	-0.21	-0.35	-0.14	-29.28	-29.3	-1.70	-8.75	-20.55	-0.85
5x3	25.3	40.2	0.11	-0.09	-0.10	21.28	11.73	-1.20	1.23	10.50	-3.48
5x4	-239.8	-151.0	-0.61	-0.37	-0.26	-53.03	-19.25	-1.88	-4.65	-14.6	1.70
5x6	-220.8	-172.3	-0.31	-0.30	-0.13	-69.26	-22.15	-1.10	-4.73	-17.09	3.01
6x1	-10.6	12.6	-0.01	-0.01	-0.01	-16.73	-6.73	-0.08	-1.20	-2.53	-5.30
6x2	-304.8	-208.0	-0.09	-0.67	-0.35	-43.30	-14.1	-0.45	-2.33	-11.78	2.90
6x3	18.1	38.3	-0.09	0.02	-0.05	0.38	4.25	1.75	2.33	1.93	4.38
6x4	19.7	46.4	0.02	0.17	0.04	-5.70	-3.73	-0.75	-0.83	-2.90	0.60
6x5	25.2	15.7	0.07	-0.07	-0.02	7.85	4.13	0.93	0.95	3.18	-0.65
LSD(0.01)	19.30	15.81	0.85	0.80	0.74	13.25	7.64	3.00	3.78	6.63	3.70

FPM= Fresh plant mass; DPM= Defoliated plant mass; PH= Plant height; BD= Basal diameter; MD= Middle diameter; DS%= Dry one meter stalk mass dry mass percentage; BM= Bast mass; CM= Core mass; BM/CM= Bast mass/ core mass

Fresh plant mass (FPM)

Tainung(6) and Endora(3) ranked first and second highest and were significantly different from all the other parents in GCA. Dowling(2) ranked the lowest and also significantly lower than other parents.

In FPM, the largest positive SCA effects was Endora(3) x Gregg(5) which was significantly different from other crosses, followed by Dowling(2) x Endora(3), Cuba108(1) x Everglades41(4). The largest different significant negative effect was measured for Tainung(6) x Dowling(2).

The GCA:SCA ratio was 0.27. It shows the SCA variance was higher than GCA variance.

Defoliated plant mass (DPM)

The highest GCA for DPM was measured for parent Tainung(6) which was significantly higher than all the other parents except Endora(3). The largest negative effect was calculated for Dowling(2), differing significantly from other parents except Everglades 41(4).

Endora(3) x Gregg(5) and Dowling(2) x Endora(3) had the highest rank for GCA, which were significantly different from the other parents. Tainung(6) x Dowling(2) had the largest significant different negative effect, followed by Gregg(5) x Dowling(2).

The ratio of GCA:SCA was 0.3, which indicated that a large part of total genetic variability in DPM was the result of non-additive gene action.

Plant height (PH)

Gregg(5) and Tainung(6) ranked first and second respectively and did not differ significantly from each other. The remaining parents Dowling(2), Endora(3), Cuba108(1), and Everglades41(4) did not differ significantly from each other. The Everglades41(4) had the lowest value.

From the SCA data, Endora(3) x Gregg(5) had the highest value, but it was not significantly different from the other crosses. The largest negative effect was for Gregg(5) x Everglades41(4) and it was not significantly lower than for other crosses.

A GCS:SCA ratio of 0.68 was calculated for PH.

Basal diameter (BD)

The largest positive GCA effect for BD was measured for Endora(3), which was not significantly different from the other parents. The smallest negative value was for Everglades41(4).

Dowling(2) x Endora(3) had the highest positive SCA effect, but it was not significantly different from the other crosses. Tainung(6) x Dowling(2) had the largest negative SCA. A common GCA:SCA ratio of 0.49 confirmed the importance of non-additive gene action.

Middle diameter (MD)

In this study, Tainung(6) and Endora(3) had the largest positive GCA effects for MD. These values did not differ significantly from other parents. Cuba108(1) ranked the lowest, but it did not differ significant from other parents.

Dowling(2) x Endora(3) had the highest positive SCA effect, but it was not significantly different from the other crosses. The largest negative effect was Tainung(6) x Dowling(2) and it was not significantly lower than other crosses. The ratio of GCA:SCA was 0.68. It indicated the non-additive gene action was significant.

Dry stalk to fresh stalk percent (DS%)

Gregg(5) ranked first respectively for measured GCA effects of DS%, on the other hand, Cuba108(1) had the smallest value of DS%.

In GCA of DS%, Endora(3) x Gregg(5) had the highest positive value which was significantly higher than zero. The lowest value of SCA value was Cuba108(1) x

Gregg(5), and it was not significantly different from other crosses. The ratio of GCA:SCA was 1.8. It indicated that additive gene action was predominant.

Bast mass (BM)

In Table 3.6, the highest GCA value of BM was for Gregg(5). But it was not significantly higher than the other parents.

Endora(3) x Gregg(5) and Dowling(2) x Gregg(5) had the two highest SCA values of the crosses. The Gregg(5) x Dowling(2) had the lowest value of all the crosses. They were not significantly different from each other. The GCA:SCA ratio of BM was small (0.41). It indicated the non-additive gene action was higher than additive gene action.

Core mass (CM)

The highest GCA for CM measured for parents was Tainung(6) and did not differ significantly from other parents. The remaining parents also did not differ significantly from one to another, Dowling(2) had the lowest value.

For the CM, the largest positive values of SCA was estimated for Endora(3) x Gregg(5), which differed significantly from all crosses except Cuba108(1) x Tainung(6). The ratio of GCA:SCA was 0.42. It indicated that non-additive gene action was significant.

Bast mass: Core mass (BM/CM)

Cuba108(1) and Tainung(6) respectively ranked the highest and lowest for GCA of BM/CM. Both of those values were not significantly different from all of the parents.

The highest positive SCA value was for Tainung(6) x Endora(3) and the smallest was for Tainung(6) x Cuba108(1). The ratio of GCA:SCA was 2.77. It indicated the additive gene action in this characteristic was dominant.

3.3.2.3 Discussion

A high positive GCA value means the parent line has high potential for generating superior offspring (Cruz and Regazzi, 1994). Significant GCA effects were found among the parents for the different characteristics estimated. The results indicated that the parent line, Tainung(6), was the best general combiner for most of the characteristics estimated except PH (plant height), DS% (Dry stalk to fresh stalk percent) and BM/CM (Bast mass: Core mass). It can be used for improvement of most yield and fiber quality characteristics. Endora(3) also had high positive GCA values for most of the yield characteristics (FPM, DPM, BD and MD). It could be used to improve yield in the breeding program. Gregg(5) was the best general combiner for BM, CM, DMSM, and DS%, which were components of fiber quality. It is a line that can be used to improve fiber quality.

Significant SCA effects were found for most of yield and quality characteristics. Endora(3) x Gregg(5) had the highest SCA effects for most of characteristics except BM/CM, and can be used in both yield and quality improvement. Dowling(2) x Endora(3) had high SCA values for most of the yield determining characteristic. Cuba108(1) x Endora(3) had the highest GCA value in BM/CM. Some crosses with high GCA parents of certain characteristics had a high tendency to improve mean performance and had high SCA effects, like parent Endora(3) [Endora(3) x Gregg(5), Dowling(2) x Endora(3)] in most of the characteristics.

In this study, GCA:SCA ratio was lower than one except for BM/CM. It indicated that a large part of the total genetic variability for most traits were the result of non-additive gene action.

3.3.3 Heritability

The broad sense (h^2_b) and narrow sense (h^2_n) heritability were estimated for all the characteristics and are listed in Table 3.8.

In all the yield related characteristics, including FPM, DPM, PH, BD, MD broad sense heritability values were very high, varying from BD (h^2_b=0.87) to MD (h^2_b=0.72), followed by BD (0.87), DPM (0.87), FPM (0.86) and PH (0.72). Other quality related

characteristics had moderate broad sense heritability values, from MSM (0.36) to BM/CM (0.24).

Discussion

High broad sense heritability indicated that the characteristics had high genetic variance, both additive and non-additive variance. In this study, every characteristics measured had high broad sense heritability. It indicated the phenotypic variation due to environmental variation which was very limited in yield determined characteristics.

Narrow sense heritability is important for breeding programs, because it estimates the relative importance of the additive portion of the genetic variance that can be transmitted to the next generation. In this case, the narrow sense heritability of all characteristics was relatively low. Falconer and Mackay (1996) stated that the lower narrow sense heritability was caused by low additive effects and high dominant gene action. These results are combined with the combining ability analysis.

Table 3.8 Estimates of heritability for various characteristics in kenaf

	FPM	DPM	PH	BD	MD	DS%	BM	CM	BM/CM
σ^2A	34461.88	15056.85	0.03	0.06	0.01	2.07	7.57	70.70	7.00
σ^2G	51457.71	24155.80	0.15	0.17	0.05	2.37	5.75	57.02	3.51
σ^2E	8383.70	3777.07	0.03	0.03	0.02	4.86	12.39	116.37	11.39
σ^2P	59841.40	27932.88	0.18	0.19	0.07	7.24	18.13	173.40	14.90
h^2b	0.86	0.87	0.83	0.87	0.72	0.33	0.32	0.33	0.24
h^2n	0.58	0.54	0.19	0.34	0.21	0.29	0.42	0.41	0.47

3.3.4 Heterosis

Mid-parent heterosis (MPH) and high-parent heterosis (HPH) was measured for all the characteristics. Estimated values were listed in Table 3.10. If the heterosis value is negative, it is indicated that there is no heterosis or a lack of heterosis.

Fresh plant mass (FPM)

All of the F1 hybrids expressed positive MPH for FHM, which ranged from 1.1% to 207.7%. The F1 hybrid Endora(3) x Dowling(2) expressed the highest MPH (207.7%). Only two F1 hybrids expressed negative HPH. The hybrid Endora(3) x Dowling(2) (196.9%) had the highest HPH, followed by Dowling(2) x Endora(3) (136.6%).

Defoliated plant mass (DPM)

Twenty-nine of the F1 hybrids had positive mid-parent heterosis. The highest heterosis was expressed by hybrid Endora(3) x Dowling(2) (204.7%). Others were positive, Endora(3) x Dowling(2) (196.7) to Gregg(5) x Tainung(6) (0.04). High parent heterosis was expressed in a range from196.7% (Endora x Dowling) to 0.04%.

Plant height (PH)

The hybrid Endora(3) x Dowling(2) (53.8%) had highest MPH, followed by Endora(3) x Gregg(5) (49.3%). Twenty-six of the 30 hybrids had positive HPH. The hybrids Endora(3) x Everglades41(4) (47.5%) and Everglades41(4) x Endora(3) (47.5%) had the highest HPH.

Basal diameter (BD)

Positive MPH was found for all the F1 hybrids for BD. The hybrid Endora(3) x Dowling(2) (72.3%) had the highest positive MPH, followed by Tainung(6) x Dowling(2) (59.6%). Twenty-six of the 30 hybrids had positive HPH. The highest heterosis was for hybrid Endora(3) x Dowling(2) (64.5%), followed by Gregg(5) x Endora(3) (48.3%).

Middle diameter (MD)

All the F1 hybrids had positive MPH for middle diameter, which ranged from 1.5 to 52.4%. The hybrid Endora(3) x Dowling(2)(68.3%) had the highest positive MPH followed by Tainung(6) x Dowling(2) (52.4%). Twenty-eight of the 30 hybrids had

positive HPH. The highest HPH was found in Endora(3) x Dowling(2)(68.3%) followed by Gregg(5) x Endora(3) (43.3%).

Dry stalk to fresh stalk percent (DS%)

Positive MPH was expressed by Gregg(5) X Endora(3) (24.6%) to Cuba108(1) x Everglades41(4) (0.2%). Six F1's had negative heterosis values. Nineteen of 30 F1 hybrids had positive HPH values. The hybrid Gregg(5) X Endora(3) (15.6%) had the highest HPH value.

Bast mass (BM)

Positive MPH was expressed by Gregg(5) x Dowling(2) (146.1%) to Gregg(5) x Tainung(6) (3.8%). The highest MPH was expressed by hybrids Gregg(5) x Dowling(2) (146.1%). Twenty-seven of 30 F1 hybrids had positive HPH values. The hybrid Gregg(5) x Dowling(2) (114.2%) had the highest HPH value, followed by Dowling(2) x Endora(3) (84.0%) and Endora(3) x Dowling(2) (82.7%).

Core mass (CM)

For core mass 28 of all 30 F1 hybrids had positive MPH. The hybrid Gregg(5) x Dowling(2) (151.9) had the highest MPH, followed by Endora(3) x Gregg(5) (130.0%). The hybrid Gregg(5) x Dowling(2) (121.6%) also had the highest positive MPH in twenty-three positive HPH values.

Bast mass: Core mass (BM/CM)

Twenty of the 30 F1 hybrids had positive MPH. The hybrid Endora(3) x Tainung(6) (24.0%) expressed the highest MPH, followed by Tainung(6) x Cuba108(1) (16.6%). Thirteen of the 30 F1 hybrids had positive HPH. The hybrid Endora(3) x Tainung(6) (22.5%) also expressed the highest HPH of 30 crosses.

Discussion

Heterosis in kenaf was strongly expressed, as reported by some scientists (Li, 2000; Qi *et al.,* 1992; Dempsey, 1963). In this study, most of crosses showed a positive mid-parent and high-parent heterosis. The characteristics that determined yield had very high MPH and HPH values, FPM (MPH from 207.7% to 1.1%; HPH from 196.9% to -13.2%), DPM (MPH from 204.7% to -7.0%; HPH from 196.7% to -21.1%). Compared to yield related characteristics, the fiber characteristics had lower mid-parent and high-parent heterosis. The three hybrids expressing the highest MPH and HPH heterosis overall, were Endora(3) x Dowling(2), Gregg(5) x Dowling(2) and Endora(3) x Gregg(5).

The heterosis of yield related characteristics was high, and they also had high heritability values and combining ability. It means those characteristics can be improved in early generations by selection. A breeding program utilizing heterosis to improve yield characteristics could be expected to be successful.

3.4 Conclusions

Significant phenotypic differences were found among the parental lines and their F1 hybrids for most of the characteristics measured. Parent Tainung(6) was the superior parent in nine of 11 characteristics measured, and parent Endora(3) showed high GCA for yield characteristics. They are excellent combiners and potential breeding material as parents for kenaf yield and fiber improvement programs.

Overall, GCA was lower compared to SCA values, this indicated that non-additive genetic effects were more important for the inheritance of those characteristics. Some crosses had significant SCA values, which can be used in hybrid breeding programs.

Of all the yield characteristics, FPM, DPM, PH BD, and MD had very high broad sense heritability. The fiber characteristics had relatively low broad sense heritability. As expected, the narrow sense heritability was lower than the broad sense heritability. Fresh plant and defoliated plant mass had the highest values, and mid-stem diameter had the smallest values. Heterosis was strongly expressed in this study. Positive mid-parent and high-parent heterosis were measured in all of the 11

measured characteristics. This indicated that considerable potential exists in this germplasm for developing hybrids. Endora(3) x Dowling(2), Gregg(5) x Dowling(2) and Endora(3) x Gregg(5) expressed the highest heterosis in most of characteristics measured. From this study it was observed that F1 kenaf hybrids did not only have high yield potential but also increased fiber quality. Therefore hybrid breeding can be used effectively to improve yield and fiber quality in kenaf.

Table 3.9 Heterosis (%) estimates of various characteristics in kenaf

	FPM		DPM		PH		BD		MD		DS%		BM		CM		BM/CM	
	MPH	HPH	MPH	HPH	MPH	HPH	MPH	HPH	MPH	HPH	MPH	HPH	MPH	HPH	MPH	HPH	MPH	HPH
1x2	1.1	-13.2	7.0	-8.5	-1.6	-1.8	2.1	-7.7	1.5	-6.8	-4.6	-7.6	8.0	-10.1	7.0	-8.3	7.4	4.1
1x3	72.9	53.1	66.8	46.0	36.8	24.1	19.8	13.1	19.7	16.9	3.1	1.2	23.8	5.5	6.9	4.7	5.6	3.7
1x4	112.8	98.7	96.6	78.9	26.6	13.6	22.9	18.8	17.4	14.2	0.2	-0.4	18.3	7.8	12.9	9.8	4.9	-5.8
1x5	117.0	116.3	86.5	84.2	27.3	17.8	22.8	18.1	18.1	17.3	-3.7	-9.0	49.2	41.4	53.3	48.6	01.8	-3.4
1x6	71.8	51.7	60.2	37.1	24.6	14.4	13.1	7.2	24.5	16.5	7.9	7.6	30.3	25.1	43.1	23.4	-10.8	-19.3
2x1	60.6	37.9	51.8	29.8	19.4	19.1	16.2	5.0	25.7	15.5	3.4	0.2	16.0	-3.5	20.9	3.5	-2.1	-5.1
2x3	145.2	136.6	125.9	120.0	44.2	31.1	54.2	47.2	47.9	39.0	7.9	6.5	89.4	84.0	74.1	58.7	8.4	2.1
2x4	81.2	65.6	82.8	70.6	37.1	23.3	13.5	5.8	18.9	12.1	15.6	12.6	46.6	32.4	49.0	24.7	-1.8	-9.2
2x5	43.4	22.8	37.5	18.9	20.5	11.2	18.2	10.8	21.2	10.7	3.0	-5.6	16.0	1.0	26.4	11.2	-5.8	-7.2
2x6	15.5	-10.5	6.3	-20.0	8.3	-0.8	6.0	-8.6	5.4	-8.8	13.6	9.7	25.8	1.3	13.4	-14.0	9.0	1.5
3x1	78.9	58.5	68.2	47.2	32.3	20.0	20.2	13.5	17.0	14.2	-6.3	-8.0	49.7	27.5	2.6	0.5	8.3	6.4
3x2	207.7	196.9	204.7	196.7	53.8	39.7	72.3	64.5	68.3	58.2	6.7	5.3	88.1	82.7	77.9	62.2	5.1	-1.0
3x4	97.8	86.9	91.7	83.5	49.2	47.5	30.4	27.2	31.7	31.2	15.5	14.0	21.1	12.3	15.9	5.4	2.8	0.7
3x5	167.5	136.4	151.6	122.6	49.3	26.3	43.9	41.3	34.7	30.7	15.6	7.3	93.8	73.1	130.0	121.1	-14.3	-20.4
3x6	100.2	59.3	89.2	45.1	25.3	5.3	24.4	11.7	20.9	10.6	16.5	14.0	53.7	26.7	25.4	2.0	24.0	22.5
4x1	120.7	106.0	105.6	87.1	39.2	25.0	16.1	12.3	29.9	26.4	10.0	9.4	33.5	21.7	45.2	41.1	-7.6	-17.1
4x2	80.7	65.1	86.7	74.3	41.1	26.9	18.3	10.3	28.8	21.4	-8.1	-10.5	26.7	14.4	11.5	-6.7	15.8	7.0
4x3	97.8	86.9	91.7	83.5	49.2	47.5	30.4	27.2	31.7	31.2	15.5	14.0	21.1	12.3	15.9	5.4	2.8	0.7
4x5	10.8	3.2	10.6	1.8	-9.2	-23.9	8.9	8.2	10.3	6.7	-8.9	-14.4	9.3	4.9	1.3	-4.4	6.3	-3.1
4x6	79.4	49.3	61.2	27.6	33.3	11.0	23.8	13.8	23.9	12.9	3.6	2.7	17.1	2.9	6.5	-5.9	9.2	8.2
5x1	89.6	89.0	84.1	81.8	21.1	12.0	32.0	26.9	7.4	6.7	-8.6	-13.7	6.4	0.9	20.2	16.5	-1.1	-2.7
5x2	159.0	121.8	138.8	106.5	37.7	27.0	49.8	40.4	41.6	29.3	15.9	6.3	146.1	114.2	151.9	121.6	-1.7	-3.1
5x3	155.6	125.8	126.7	100.6	39.3	17.8	51.2	48.3	47.8	43.3	24.6	15.6	76.1	57.3	71.3	64.7	3.8	-3.6
5x4	117.9	102.8	100.4	84.6	46.5	22.8	39.5	38.7	46.2	41.3	5.0	-1.5	72.0	65.0	75.1	65.2	-2.7	-11.4
5x6	16.8	3.4	0.04	-15.3	3.8	3.0	3.0	-5.9	6.9	0.6	5.0	-0.5	3.8	05.3	-4.3	-19.6	7.8	-1.0
6x1	75.7	55.1	54.6	32.3	25.5	15.2	13.8	7.9	25.8	17.6	8.5	8.2	43.6	37.9	53.8	32.7	16.6	5.5
6x2	141.6	87.1	111.3	59.0	28.2	17.5	59.6	37.6	52.4	31.8	17.2	13.2	56.6	26.1	70.2	29.1	-6.6	-13.0
6x3	92.9	53.5	70.3	30.6	33.0	11.8	22.5	10.0	27.3	16.5	2.6	0.4	23.6	1.9	16.7	-5.0	-0.9	-2.1
6x4	71.9	43.0	38.9	10.0	31.5	9.5	11.1	2.1	18.1	7.6	9.5	8.5	27.2	11.7	18.5	4.8	5.7	4.8
6x5	7.7	4.6	-7.0	-21.2	-1.1	-1.9	7.9	-1.4	9.4	2.9	-1.7	-6.9	-7.3	-15.5	-18.1	-31.2	11.2	2.2

Chapter 4

Genotype x environment interaction and stability analysis in kenaf (*Hibiscus cannabinus* L.)

4.1 Introduction

In the past, plant breeding programs mostly focused on developing high yielding cultivars. Recently, stable and sustainable yields under various environmental conditions have consistently gained importance over only increased yield. The development of cultivars, which are adapted to a wide range of diversified environments, is the ultimate aim of plant breeders in a crop improvement program (Muhammad *et al.*, 2003). Genotype x Environment (GXE) interactions are an important issue to agronomists, who transfer a new variety from another environment. The adaptability of a variety over diverse environments is commonly evaluated by the degree of its interaction with different environments in which it is grown. A variety is considered to be more stable if it has a high mean yield but a low degree of fluctuation in yielding ability when planted over diverse environments (Purchase, 1997).

The basic cause for differences between genotypes in their yield stability is a wide occurrence of GXE interaction. The ranking of the variety depends on the particular environmental conditions in which it is grown. The environment is usually indicated as all non-genetic factors that influence expression of characteristics. It should include water, nutrition, temperature, and diseases that influence the growth of plants and therefore influence the expression of characteristics (Basford and Cooper, 1998)

GXE interactions are important facts in cultivar evaluations. GxE interaction is considered quantitative effect (Ramagosa and Fox, 1993; Baker, 1988), which is composed of genotype (G) x location (L), genotype (G) x year (Y), and genotype (G) x location (L) x year (Y) constituents. Simmonds and Smartt (1999) reported that G x Y was larger than GxE, although both were nearly equivalent for switchgrass biomass yield. If the GxY component is larger, then multiple year evaluations are needed. This will definitely slow down a breeding program. If the GxL is higher, the specific adaptation is exploitable by sub-dividing the regions into homogenous sites that minimizes G x E within regions (Baker, 1988).

The concept of stability has been defined in several ways and several biometrical methods, including univariate and multivariate ones, have been developed to assess stability (Lin and Binns, 1988; Becker and Leon, 1988; Crossa 1990; Mevlut *et al.*, 2005). Bernardo (2002) and Eberhart and Russell (1966) stated that stability can be assessed in many ways, the more common being a regression of genotype performance on an environmental index. A number of statistical methods are designed to evaluate phenotype stability. The additive main effect and multiplicative interaction (AMMI) model is effective for gaining accuracy in stability analysis. AMMI is the first choice when main effects and interaction are both important (Zobel *et al.*, 1988).

Kenaf is a new crop to South Africa, and few breeding programs have been done up to now. The aim of this study was to assess the genotype x environment interaction and stability of nine imported kenaf cultivars in different environments, to determine the best performance and most stable cultivars for commercial production in South Africa.

4.2 Materials and methods

4.2.1 Materials

Table 4.1 Kenaf genotypes used for G x E interaction and stability analysis

Entry	Genotype	Origin
1	Cuba 108	Spain
2	Dowling	USA/Mexico
3	El Salvador	Spain
4	Endora	Spain
5	Everglades 41	Spain
6	Everglades 71	Spain
7	Gregg	USA/Mexico
8	SF 459	Spain
9	Tainung 2	USA/Mexico

Nine genotypes listed in Table 4.1 were evaluated over a two year period from 2003 to 2005 in two environments in the Winterton area, in the Kwazulu - Natal Province.

4.2.2 Trial design

A randomized complete block design was used with four replicates. Each plot was 1.5 x 9 m with six rows of plants. The interrow spacing was 25 cm and the seed was sown every 10 cm in the row by hand. Two trials were planted in different locations close to Winterton. One is next to the Tugela river on the road to Ladysmith, and a second in the Drakensberg mountains about 30 km from Winterton. The Tugela farm was named location1 and the Drakensberg farm was named Location 2. The Tugela farm falls in the Dry Tall Grassveld with an annual rainfall of 666 – 745 mm. Summers are warm to hot and winters cool with cold spells. The Drakensberg farm falls in the Montane veld Bioresource group with an annual rainfall of 900mm to over 1400 mm. Summers are cool and winters mild with severe frost and snow at times (Camp, 1997). The first season trials were planted early in November 2003 and were harvested in April 2004, and the second season trials were planted late in November 2004 and were harvested in April 2005. At the Tugela farm no-till was practiced and in the first year the seed was planted in canola residuals and in the second year in maize residuals. The Tugela trials were irrigated in both seasons. At the Drakensberg location the trials were planted in prepared seed beds, but the trials were grown under rain-fed conditions in both seasons. These two locations were chosen as this is the designated area for future production, and this is also where a factory will be built to produce pulp. Fertilization was done according to soil analysis. In the first year replanting of missing plants that did not germinate was done after a month. In the second year replanting was not possible due to logistics

4.2.3 Characteristics measured

The plants were manually harvested as soon as 50% of the plants were flowering. Four rows in the middle of each plot were harvested, and 1 m at both sides of these rows was discarded to eliminate side-row effects. Therefore the final plot size was 7 m^2.

According to the SPDG (Sustainable Projects Development Group of the UK) suggestions and the literature (Pace 1998; Shamsuddin *et al* 2001; Chen *et al.* 2004), the following characteristics were measured:

Fresh plant yield

After cutting, all plants of each plot were weighed. A factor of 1.429 was used to convert yield per plot to ton per hectare.

Defoliated stalk yield

After measuring the fresh plant yield, 10 plants of each plot were defoliated and weighed.

Plant height

Ten plants were measured. The mean of 10 measurements/ plot was calculated.

Basal diameter

The diameter of the bottom of the plant was measured. The mean of 10 measurements/ plot was calculated.

Middle diameter

The diameter of the middle of plant was measured and the mean of 10 measurements/ plot was calculated.

Dry stalk yield

One meter of two stalks from each plot was taken from the middle of the plant. They were weighed immediately after cutting, to determine fresh one meter stalk weight (MSM). They were dried for 5 days at 65^{o}C, then weighed again to get dry one meter stalk mass: (DMSM) The ratio of MSM and DMSM was percentage dry mass. Dry stalk yield was calculated in this way.

4.2.4 Statistical analysis

A range of statistical analyses was conducted using Agrobase (2000). The following statistical analyses were performed:

1. Analysis of variance
2. Stability analysis in:
    1) Cultivar superiority measure (Lin and Binns, 1988)
    2) Ecovalence (Wricke, 1962)
    3) Stability variance (σ^2_i) measure (Shukla, 1972)
    4) AMMI (Gauch, 1988; Zobel, 1988)

4.3 Results and discussion

4.3.1 Analysis of variance

4.3.1.1 Simple ANOVA for each location of 2003/2004 (year 1)

The data of year 1 was analyzed and reported by Coetzee (2004), and for this reason is only listed here and not discussed again. It was, however, used in the combined and stability analyses. Two trails in different location were separately analyzed. The mean squares of different traits were listed in Table 4.2. It indicated significant (P<0.05) differences among the entries of plant length in Location 1. Highly significant (P<0.01) differences among blocks for plant length was observed in Location 1. Highly significant (P<0.01) differences were found among entries for basal diameter, middle diameter and plant length were observed in Location 2.

Table 4.2 Mean squares of traits of nine kenaf cultivars evaluated at two locations during the 2003/04 season

Source		Df	Fresh yield t/ha	Defol yield t/ha	Dry yield t/ha	Basal-diameter	Mid-diameter	Length
Loc1	Entry	8	797.30	466.95	106.55	0.22	0.36	677.36*
	Block	3	679.79	445.01	83.75	1.23	0.08	1478.25**
Loc2	Entry	8	525.19	338.61	29.47	2.23**	1.02**	1256.61**
	Block	3	457.29	402.83	35.74	0.22	0.21	176.74

*** P<0.01,* P<0.05*

4.3.1.2 Simple ANOVA for each location of 2004/2005 (year 2)

The trials in different locations were analysed separately. The mean squares of different traits were listed in Table 4.3. It indicated significant (P<0.05) differences among the entries for plant length in Location 1. Highly significant (P<0.01) differences among blocks for basal diameter and middle diameter was observed in location 1. This indicates large differences in stem characteristics between replications in the trials. No significant differences occurred in Location 2.

Table 4.3 Mean squares of traits of nine kenaf cultivars evaluated at two locations during the 2004/05 season

source		Df	Fresh yield t/ha	Defol yield t/ha	Dry yield t/ha	Basal-diameter	Mid-diameter	length
Loc1	Entry	8	210.44	138.11	14.11	0.34	0.62	541.30*
	Block	3	404.99	231.72	18.40	2.30**	1.83**	256.19
Loc2	Entry	8	596.39	299.45	20.77	0.26	0.05	397.07
	Block	3	292.33	147.70	12.95	0.04	0.09	756.48

*** P<0.01,* P<0.05*

Table 4.4 Mean values for six traits of nine kenaf cultivars evaluated at two environments for the 2003/2004 season

Entry	*Fresh yield(t/ha)*		*Defol yield (t/ha)*		*Dry yield (t/ha)*		*Basal-diameter*		*Mid-diameter*		*Length*	
	Loc1	**Loc2**	**Loc1**	**Loc2**	**Loc1**	**Loc2**	**Loc1**	**Loc2**	**Loc1**	**Loc2**	**Loc1**	**Loc2**
Cuba 108	100.36	84.47	79.72	69.26	20.38	13.49	7.65	8.15	6.25	6.53	317.25	335.75
Dowling	126.08	74.82	102.12	64.23	28.09	13.08	7.78	6.63	6.08	5.35	319.75	305.00
El Salvador	135.36	102.40	108.14	83.88	26.25	17.04	7.78	8.03	6.60	6.58	341.75	349.25
Endora	104.11	98.25	84.38	80.91	23.62	18.37	8.20	8.90	6.68	7.10	335.50	357.75
Everglades 41	123.75	90.08	95.30	73.59	26.07	14.52	8.20	7.67	6.63	6.40	334.25	336.00
Everglades 71	115.54	95.00	90.88	78.52	23.99	18.26	7.88	7.58	6.50	5.90	334.75	327.75
Gregg	110.54	71.61	87.44	59.60	22.78	11.09	7.63	8.03	5.88	6.20	309.00	351.50
SF 459	98.75	71.97	81.31	57.95	22.50	11.53	7.80	7.65	6.33	6.23	313.00	320.00
Tainung 2	134.65	87.72	106.92	70.05	38.06	14.95	7.55	9.15	5.98	6.75	344.00	355.00
Mean	116.57	86.26	92.91	70.89	25.75	14.70	7.83	7.98	6.32	6.34	327.69	337.56
LSD (0.05)	23.41	19.92	19.50	16.91	8.48	4.55	0.83	0.66	0.52	0.42	19.19	17.05

Table 4.5 Mean values for six traits of nine kenaf cultivars evaluated at two environments for the 2004/2005 season

Entry	*Fresh yield(t/ha)*		*Defol yield (t/ha)*		*Dry yield (t/ha)*		*Basal-diameter*		*Mid-diameter*		*Length*	
	Loc1	**Loc2**	**Loc1**	**Loc2**	**Loc1**	**Loc2**	**Loc1**	**Loc2**	**Loc1**	**Loc2**	**Loc1**	**Loc2**
Cuba 108	68.47	68.15	57.30	50.36	14.79	12.41	7.63	7.78	5.85	5.90	354.00	350.00
Dowling	63.18	41.93	54.81	33.85	13.87	8.58	6.95	7.13	4.45	5.58	329.25	338.25
El Salvador	73.75	58.14	61.14	41.54	16.61	11.25	7.18	7.53	5.18	5.53	349.50	352.25
Endora	70.75	62.18	59.66	46.97	15.64	12.04	7.40	7.73	5.45	5.78	355.00	345.00
Everglades 41	68.50	49.15	58.47	36.37	15.94	10.00	7.25	7.30	5.40	5.73	357.75	329.50
Everglades 71	64.32	41.57	53.87	31.84	15.54	8.36	7.40	7.00	5.35	5.60	342.75	353.00
Gregg	70.57	59.89	59.73	44.96	16.02	11.42	7.50	7.33	5.35	5.68	353.25	355.75
SF 459	80.65	58.86	66.70	43.83	19.34	10.48	7.90	7.43	5.58	5.68	345.25	329.75
Tainung 2	54.68	30.47	45.36	22.99	12.56	5.19	7.73	7.28	5.00	5.63	371.75	339.00
Mean	68.32	52.26	57.45	39.19	15.59	9.97	7.44	7.39	5.29	5.68	350.94	343.61
LSD (0.05)	16.88	21.13	14.20	16.14	4.52	4.23	0.86	0.44	0.84	0.48	15.84	24.03

4.3.1.3 Analysis at two localities in 2004/2005

Mean values for six traits of those kenaf cultivars across two environments in 2004/2005 season were listed in Table 4.5. It indicated that trait values in Location 1 were obviously higher than Location 2, especially in yield traits, including fresh yield, defoliated stem yield and dry yield. It was probably because Location 1 was irrigated and Location 2 was under dry land conditions. Therefore, in order to get higher fiber yield, it is better to plant kenaf under irrigation conditions.

Fresh yield

The analysis of variance (ANOVA) results for fresh yield were listed in Table 4.6 and Table 4.7. There were highly significant differences in fresh yield among the locations (*P*=0.001), and significant differences among the entries (*P*=0.012). The entry x location MS was not significant. Location 1 yielded higher than Location 2.

Cultivar SF 459 gave the highest fresh field in the combined analysis of variance, followed by Cuba108 and Endora. SF 459 yielded significantly better than Dowling and Tainung 2.

Defoliated stem yield

The ANOVA results (Table 4.6) for defoliated stem yield at each location show that there were highly significant differences (*P*=0.001) between locations and entries, but there was no significant stem yield entry x location interaction. Defoliated stem yield in Location 1 was higher than Location 2.

The mean values for defoliated stem yield of nine kenaf cultivars are given in Table 4.7. The cultivar which had the highest defoliated stem yield value was SF 459, but the yield was not significantly better than Cuba 108 and Endora which performed second and third best. However, SF 459 was significantly better than Dowling, Everglades 71 and Tainung2.

Dry stalk yield

The combined ANOVA for dry stalk yield over locations show that there were significant differences between the locations, but not between the entries and there

was no entry x location interaction (Table 4.6). Dry stalk yield value in Location 1 was higher than Location 2.

SF 459 gave the highest dry stalk yield in the combined analysis, followed by El Salvador and Endora. The worst performing cultivar was Tainung 2, which was significantly lower than other cultivars except Dowling (Table 4.7).

Basal diameter

No significant differences were observed among the entries, location and entry x location of basal diameter values in analysis of variance (Table 4.6). The mean values of basal diameter in Location 1 were higher than Location2.

Cuba 108 gave the highest basal diameter value in combined analysis, followed by SF 459 and Endora. The worst performance cultivar was Dowling (Table 4.7).

Middle diameter

There were highly significant differences in middle diameter between the locations (P=0.001), but the other components were not significant (Table 4.6). Location 1 had a higher average than Location 2.

The mean values for middle diameter of nine kenaf cultivars were illustrated in Table 4.7. The cultivar which had the highest middle diameter value was Cuba108, but the yield was not significantly better than that of SF 459 and Endora which performed second and third best. However, SF 459 was significantly better than El Salvador, Tainung 2 and Dowling.

Plant height

No significant differences were observed among the entries, location and entry x location of plant high values in analysis of variance (Table 4.6). The mean values of plant height in Location 1 were higher than Location 2. Tainung 2 gave the highest plant height value in the combined analysis, followed by Gregg and Cuba 108. They were significantly higher than SF 459 and Dowling. The worst performing cultivar was Dowling (Table 4.7).

Table 4.6 Mean squares of various traits of kenaf cultivars in combined analysis across locations in 2004/2005

Source	Df	Fresh yield *t/ha*	Defol yield *t/ha*	Dry yield *t/ha*	Basal-diameter *cm*	Mid-diameter *cm*	Length *cm*
Entry	8	678.15*	375.65*	26.92	1.75	0.47	452.68
Location	1	4642.63**	6000.42**	568.46**	0.045	2.68*	968.00
Bloc x Loc	6	348.16	189.71	15.67	1.17**	0.96**	506.33
Entry x Loc	8	128.69	61.90	7.95	0.22	0.21	485.69

*** p ≤ 0.01, * p ≤ 0.05*

Table 4.7 Mean values for various traits of nine kenaf genotypes evaluated in 2004/2005

Entry	Fresh yield		Defol yield		Dry yield		Basal-diameter		Mid-diameter		length	
	t/ha	rank	t/ha	rank	t/ha	rank	Cm	rank	Cm	rank	Cm	rank
Cuba108	68.31	2	53.83	2	13.60	5	7.70	1	5.88	1	352.00	3
Dowling	52.56	8	44.33	7	11.22	8	7.04	9	5.01	9	333.75	9
El Salva	65.95	4	51.34	5	13.93	2	7.35	6	5.35	7	350.88	4
Endora	66.47	3	53.32	3	13.84	3	7,56	3	5.61	3	350.00	5
Everg 41	58.82	6	47.42	6	12.97	6	7.28	7	5.56	4	343.63	7
Everg 71	52.95	7	42.85	8	11.95	7	7.20	8	5.48	6	347.88	6
Gregg	65.23	5	52.35	4	13.72	4	7.41	5	5.51	5	354.50	2
SF459	69.75	1	55.26	1	14.91	1	7.66	2	5.63	2	337.50	8
Tainung2	42.57	9	34.17	9	8.88	9	7.50	4	5.31	8	355.38	1
Mean	60.29		48.32		12.78		7.41		5.48		347.28	
CV (%)	25.7		25.8		28.1		6.32		8.97		4.62	
LSD(0.05)	12.99		10.46		3.01		0.39		0.41		13.47	

4.3.1.4 ANOVA across localities and years

A combined analysis of variance was carried out across two locations and different years. The results were listed in Table 4.8 and Table 4.9. The value of fresh yield, defoliated stem yield, and dry stalk yield for two years and combined analysis were shown in Fig 4.1, Fig 4.2, and Fig 4.3.

Fresh yield

There were highly significant differences in the fresh yield between the years, and localities, and there was significant year x locality and entry x year interaction (Table 4.8). The 2003/04 season was significantly better with a mean yield of 101.41 t/ha than 2004/05, which had mean fresh yield of 60.29 ton per hectare. This could be partly due to the later planting date in the second season, and the fact that replanting was done in the first season to compensate for seed that did not germinate. The interaction of entry x year was highly significant. It indicated that the performances of the entries were significantly affected by different seasons (Table 4.8).

El Salvador gave the highest fresh yield value (92.21 t/ha) in a combined two year analysis, which was significantly better than other cultivars except Endora. Dowling gave the lowest fresh yield (76.5 t/ha) in two years (Table 4.9).

Defoliated stalk yield

There were highly significant differences in the defoliated stalk yield between the years, and localities, and there was significant entry x year interaction. The 2003/04 season was significantly better with mean defoliated stem yield of 81.90 ton per hectare than 2004/05, which had mean yield of 48.32 ton per hectare. The interaction of entry x year was significant. It indicated that the performance of the entries was highly affected by different seasons.

El Salvador gave the best defoliated stalk yield value (73.67 t/ha) in a combined two year analysis, which was significantly better than the other cultivars except Endora. Tainung 2 gave the lowest fresh yield (61.33 t/ha) in two years, but it was not significantly lower than other cultivars except El Salvador (Table 4.9).

Dry stalk yield

There were highly significant differences in the dry stalk yield between the years, localities, and among the interactions of entry x year, and the interactions of year x localities. The 2003/04 season was significantly better with mean dry stalk yield of 20.67 t/ha than 2004/05, which had mean fresh yield of 12.78 t/ha. The interaction of entry x year was highly significant. It indicated that the performances of the entries were significantly affected by different seasons (Table 4.8).

El Salvador gave the best dry stalk yield value (17.78 t/ha) in a combined two year analysis, followed by Tainung 2 (17.69 t/ha) and Endora (17.42 t/ha). Cuba 108 gave the lowest fresh yield (15.27 t/ha) in two years, but it was not significantly lower than other cultivars (Table 4.9).

Table 4.8 Mean squares for various characteristics for nine kenaf cultivars across localities and years

Source	Df	Fresh yield (t/ha)	Defol yield(t/ha)	Dry yield (t/ha)
Entry	8	405.358	225.881	14.931
Loc	1	19355.302**	14602.910**	2499.667**
Year	1	60883.095**	40593.855**	1996.005**
Entry x Loc	8	412.500	238.755	43.615
Entry x Year	8	1165.010**	684.404*	86.897**
Year x Loc	1	1828.703*	127.588	264.984**
Entry x Year x Loc	8	146.454	94.071	25.449
Bloc x Year x Loc	12	458.350	306.815	37.710

*** P<0.01,* P<0.05*

Table 4.9 Means of the different traits for nine kenaf cultivars across localities and years

cultivar	Fresh yield		Defol yield		Dry yield	
	t/ha	rank	t/ha	rank	t/ha	rank
Cuba108	80.36	4	64.16	4	15.27	9
Dowling	76.50	9	63.75	6	15.90	7
El Salva	92.41	1	73.67	1	17.78	1
Endora	83.82	2	67.98	2	17.42	3
Everg 41	82.87	3	65.93	3	16.63	4
Everg 71	79.11	5	63.78	5	16.53	5
Gregg	78.15	6	62.93	7	15.33	8
SF459	77.56	7	62.44	8	15.96	6
Tainung2	76.88	8	61.33	9	17.69	2
Mean	80.85		65.11		16.50	
CV (%)	20.75		21.26		28.60	

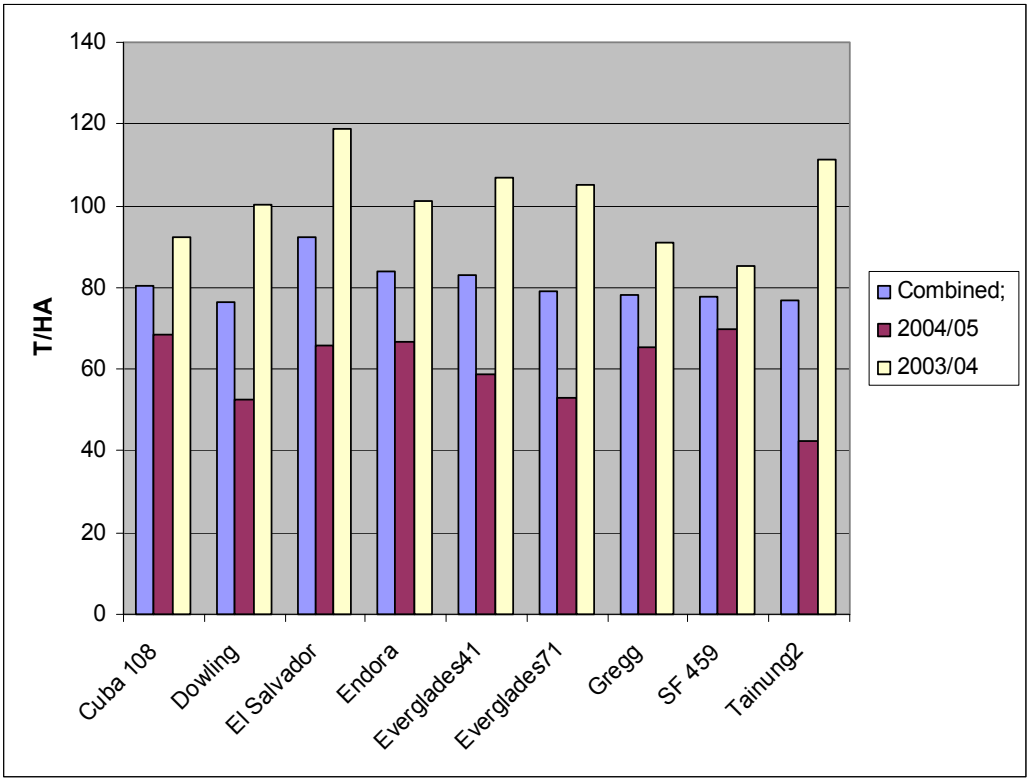

Fig. 4.1 Fresh yield of kenaf cultivars for the 2003/04, 2004/05 and combined analysis

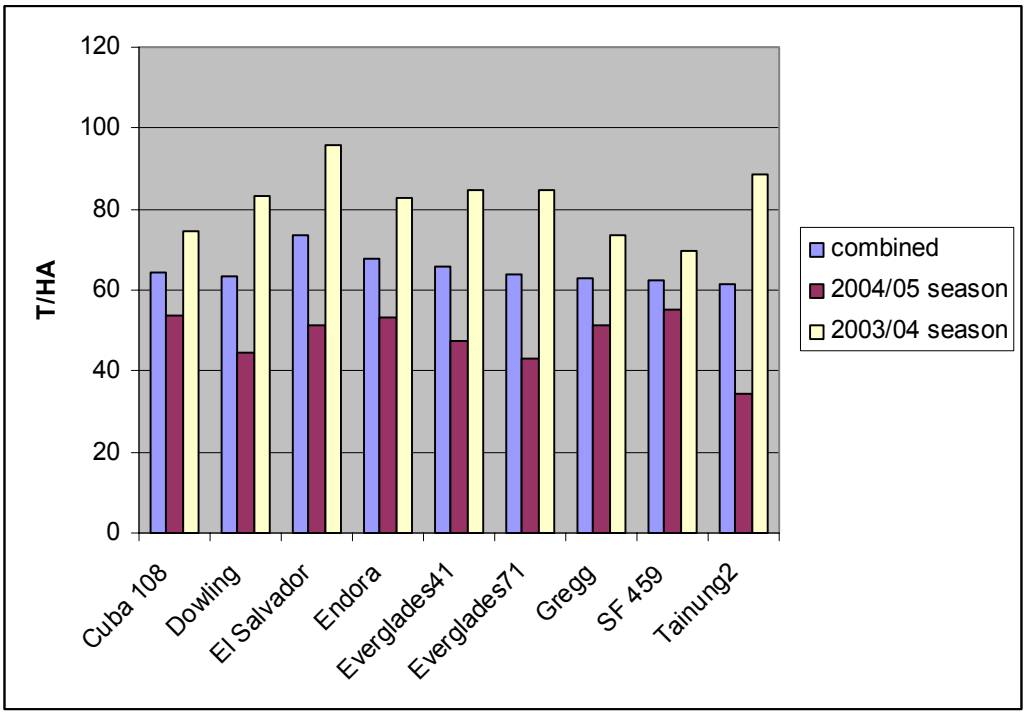

Fig 4.2 Defoliated stem yield of kenaf cultivars for the 2003/04, 2004/05 and combined analysis

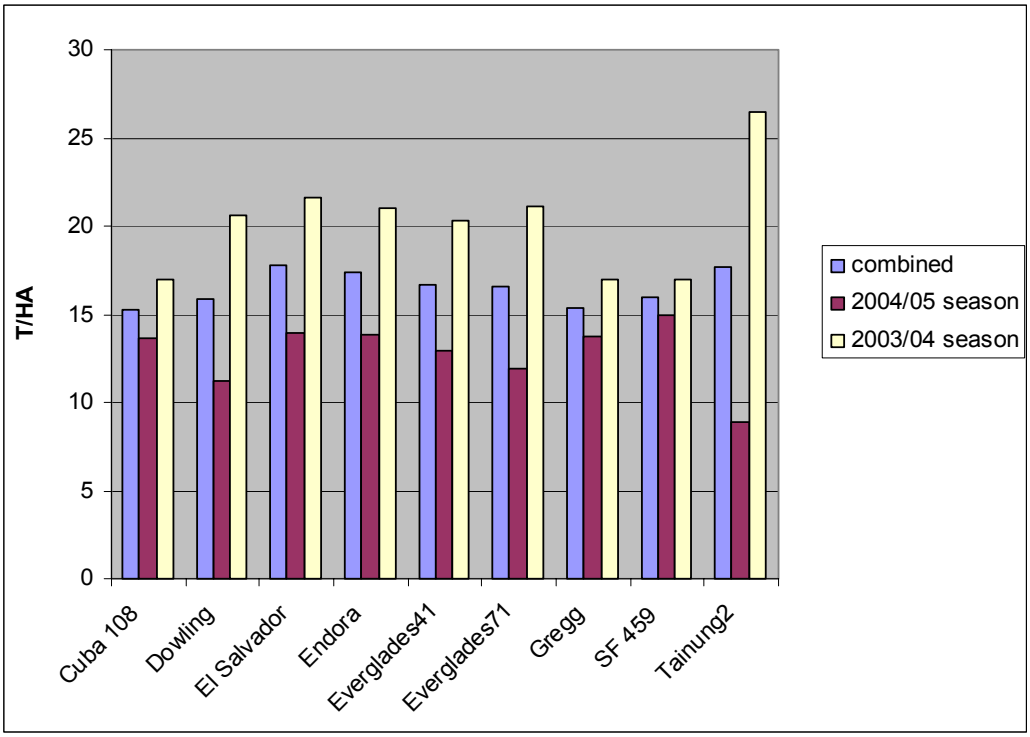

Fig 4.3 Dry yield of kenaf cultivars for the 2003/04, 2004/05 and combined analysis

4.3.2 Stability analysis

Stability analysis of the nine kenaf cultivars was done using four statistical procedures in Agrobase (2000).

a) Lin and Binns cultivar superiority measure

According to Lin and Binns (1988), the superiority measure (Pi) of cultivars is measured by squares of differences between entry mean and maximum entry mean, summed and divided by twice the number of locations. Genotypes with a low Pi value are stable. The separate analyses for irrigated (Table 4.10) and dryland (Table 4.11) conditions was done only for Lin and Binns (1988) stability measurement to determine if the results were different compared to that for combining the irrigated and dry-land data within seasons.

Table 4.10 Lin and Binns (1988) cultivar superiority measure (Pi) ranks of kenaf genotypes tested under irrigated conditions of 2003/04 and 2004/05 seasons

cultivar	*Fresh yield* (t/ha)	*Rank*	*Defoliated yield* (t/ha)	*Rank*	*Dry yield* (t/ha)	*Rank*
Cuba 108	239.52	9	159.99	9	66.18	9
Dowling	73.37	3	37.76	2	29.73	3
El Salvador	13.92	1	11.14	1	30.48	4
Endora	183.21	7	106.46	7	41.19	7
Everglades41	49.70	2	41.45	3	28.53	2
Everglades71	111.37	4	78.54	5	36.89	5
Gregg	120.23	6	80.18	6	41.41	8
SF 459	223.49	8	120.17	8	40.48	6
Tainung 2	112.45	5	76.11	4	7.67	1

The cultivar superiority measure (Pi) for yield characteristics of nine kenaf cultivars under irrigated conditions was listed in Table 4.10. For fresh yield and defoliated yield, El Salvador, Everglades 41 and Dowling were stable in different years, and they ranked in the first three positions. For dry fiber yield, Tainung 2 had the lowest Pi value, followed by Everglades 41, Dowling and El Salvador. Combined for these 1three traits, El Salvador and Everglades 41 were stable cultivars under the irrigated conditions.

Table 4.11 Lin and Binns (1988) cultivar superiority measure (Pi) ranks of kenaf genotypes tested under dryland conditions of 2003/04 and 2004/05 seasons

Cultivar	*Fresh yield*(t/ha)	*Rank*	*Defoliated yield* (t/ha)	*Rank*	*Dry yield* (t/ha)	*Rank*
Cuba 108	64.27	3	46.27	3	14.64	8
Dowling	249.43	8	117.96	7	15.28	9
El Salvador	22.67	2	18.97	2	6.52	4
Endora	12.96	1	7.56	1	4.19	1
Everglades41	88.14	4	52.96	4	6.11	3
Everglades71	128.29	5	63.48	5	4.24	2
Gregg	170.02	7	103.74	6	9.68	6
SF 459	168.90	6	119.36	8	8.60	5
Tainung 2	272.55	9	156.79	9	10.62	7

In Table 4.11, the cultivar superiority measure (Pi) for yield characteristics of nine kenaf cultivars under dryland conditions was listed. Endora was the most stable cultivar, followed by El Salvador.

In the analysis of irrigated and dryland data combined within seasons, El Salvador, Everglades 41 and Endora in that order, were ranked the most stable across the two seasons. SF 459 and Tainung 2 were unstable cultivars. For dry yield, Tainung 2 and El Salvador had low Pi values, and they were stable across the environments. Cuba 108 was an unstable cultivar (Table 4.12).

Table 4.12 Lin and Binns (1988) cultivar superiority measure (Pi) ranks of kenaf genotypes tested in the 2003/04 and 2004/05 seasons

Cultivar	*Fresh yield*(t/ha)	*Rank*	*Defoliated yield* (t/ha)	*Rank*	*Dry yield* (t/ha)	*Rank*
Cuba 108	211.8415	5	138.6926	7	44.6153	9
Dowling	229.8509	7	104.5458	5	21.5066	3
El Salvador	18.4476	1	13.5813	1	18.7508	2
Endora	140.8845	3	79.2605	3	27.7836	5
Everglades41	99.3792	2	66.8025	2	21.9800	4
Everglades71	177.4997	4	104.2651	4	28.5939	6
Gregg	216.6872	6	136.9399	6	37.3165	8
SF 459	294.0427	9	179.3964	9	36.5567	7
Tainung 2	299.7463	8	174.6808	8	13.7174	1

b) Wricke's ecovalence model

Wricke (1962) proposed using the contribution of each genotype to the genotype x environment interaction sum of squares as a stability measure, and defined this concept as ecovalence (Wi). The genotypes with small ecovalence (Wi) will have small deviations from the mean across the environments and be considered more stable.

The results from Wricke's ecovalence analysis (Wi) for three traits were listed in Table 4.13. For fresh yield, Everglades 41 followed by El Salvador and Everglades 71 were the most stable cultivars. Everglades 41 was also the most stable cultivar for defoliated yield, followed by Everglades 71 and El Salvador. For dry yield,

Everglades 41 was the most stable cultivar, followed by El Salvador and Dowling. Tainung 2 and SF 459 were the most unstable cultivars in these three trait analyses.

Table 4.13 Wricke's ecovalence value and ranks for nine kenaf genotypes tested in the 2003/04 and 2004/05 seasons

cultivar	*Fresh yield* (t/ha)	*Rank*	*Defoliated yield* (t/ha)	*Rank*	*Dry yield* (t/ha)	*Rank*
Cuba 108	517.4067	7	297.8750	7	30.7481	7
Dowling	278.4886	4	157.1751	4	11.5620	3
El Salvador	143.0139	2	126.3150	3	1.7926	2
Endora	368.1349	6	205.5694	6	18.9404	6
Everglades41	59.6282	1	19.2892	1	0.1956	1
Everglades71	195.5982	3	122.0963	2	18.3448	4
Gregg	285.1802	5	176.9342	5	18.6413	5
SF 459	673.7203	8	380.8551	8	33.7972	8
Tainung 2	926.7858	9	548.3653	9	177.8886	9

c) Shukla's procedure of stability variance

In Shukla's (1972) stability variance procedure, the stable genotype has the lowest stability variance (σ^2_i) value.

For the fresh yield the most stable genotype was Everglades 41, followed by El Salvador and Everglades 71 (Table 4.14). Tainung 2 was regarded as an unstable cultivar. For defoliated yield, Everglades 41 was the most stable genotype, Everglades 71 and El Salvador ranked the second and third. Tainung 2 was the most unstable cultivar. For dry yield, El Salvador was evaluated as the most stable genotype, followed by Everglades 41. Tainung 2 ranked as the most unstable cultivar for dry yield.

Table 4.14 Shukla's stability variance value and ranks for nine kenaf genotypes evaluated in the 2003/04 and 2004/05 seasons

Genotype	*Fresh yield (t/ha)*		*Defol yield(t/ha)*		*Dry yield (t/ha)*	
	Stability variance	**Rank**	**Stability variance**	**Rank**	**Stability variance**	**Rank**
Cuba 108	804.889	7	462.203	7	45.285	7
Dowling	395.315	4	221.003	4	12.394	3
El Salvador	163.073	2	168.100	3	-4.353	1
Endora	548.994	6	303.965	6	25.043	6
Everglades41	20.126	1	-15.373	1	-7.091	2
Everglades71	253.217	3	160.868	2	24.022	4
Gregg	406.786	5	254.876	5	24.530	5
SF 459	1072.855	8	604.455	8	50.512	8
Tainung 2	1506.681	9	891.615	9	297.526	9

d) Additive main effects and multiplicative interaction (AMMI) model

The IPCA scores of a genotype in the AMMI analysis are an indication of the stability of the genotype over environments. The more IPCA scores approximate to zero, the more stable genotype is over all environments sampled (Gauch and Zobel, 1988) (Table 4.15).

Fresh yield

In the ANOVA from AMMI, environments and genotype x environment interaction were highly significant ($P<0.001$) (Table 4.15). The G x E interaction was partitioned into three interaction principle component axis (IPCA). The IPCAs are ordered according to their importance. Only the IPCA 1 axes was significant and explained 77.44% of the total G x E interaction sums of squares percentage. The second IPCA (IPCA 2) explained 18.59% of the total G x E interaction sums of squares percentages. However, it was not significant (Table 4.15)

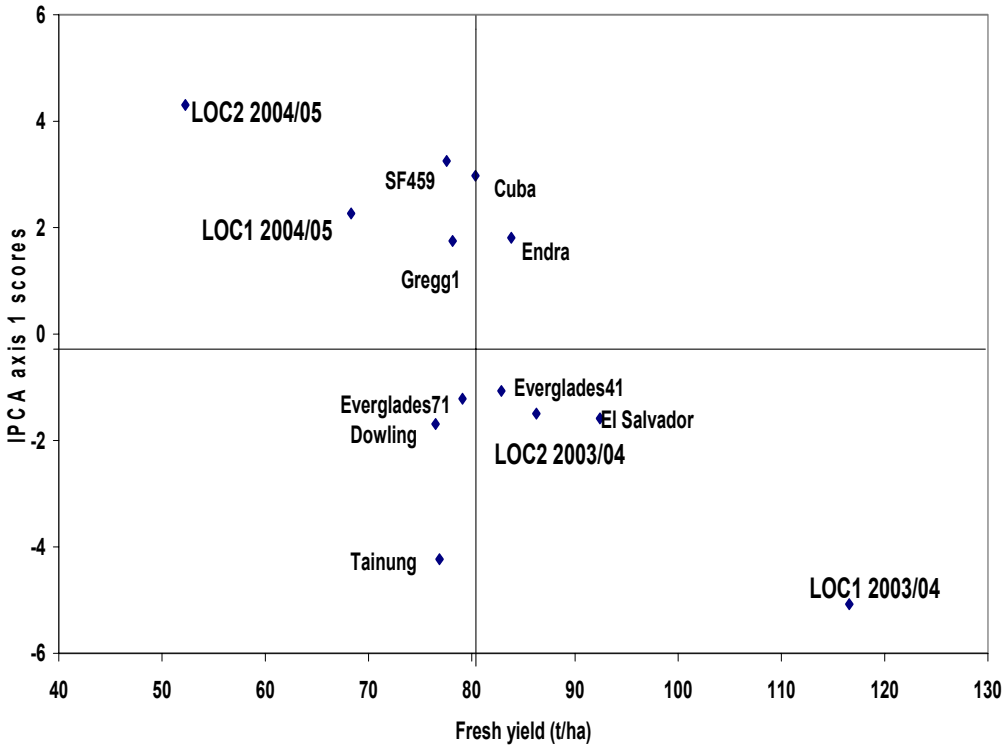

Fig. 4.4 AMMI biplot for fresh yield means (t/ha) and IPCA 1 scores

The cultivar biplot is the mean fresh yield value across different seasons of two locations

From the AMMI biplot for fresh yield (Figure 4.4), when the IPCA 1 score and means were taken into consideration, Everglades 41, Everglades 71 and El Salvador were the most stable cultivars over the range of environments. El Salvador was stable and adapted to high yielding environments. Tainung 2 was an unstable genotype with low fresh yield.

Defoliated stem yield

For the defoliated yield, this analysis showed that environments were highly significant ($P<0.001$), genotype x environment interaction was significant ($P<0.005$). The ANOVA table indicated that the G x E interaction was partitioned into three interaction principle component axis (IPCA). The IPCAs are ordered according to their importance. Only the IPCA 1 axes was significant and explained 74.91% of the total G x E interaction sums of squares percentage. The second IPCA (IPCA 2)

explained 21.64% of the total G x E interaction sums of squares percentage, however it was not significant (Table 4.15).

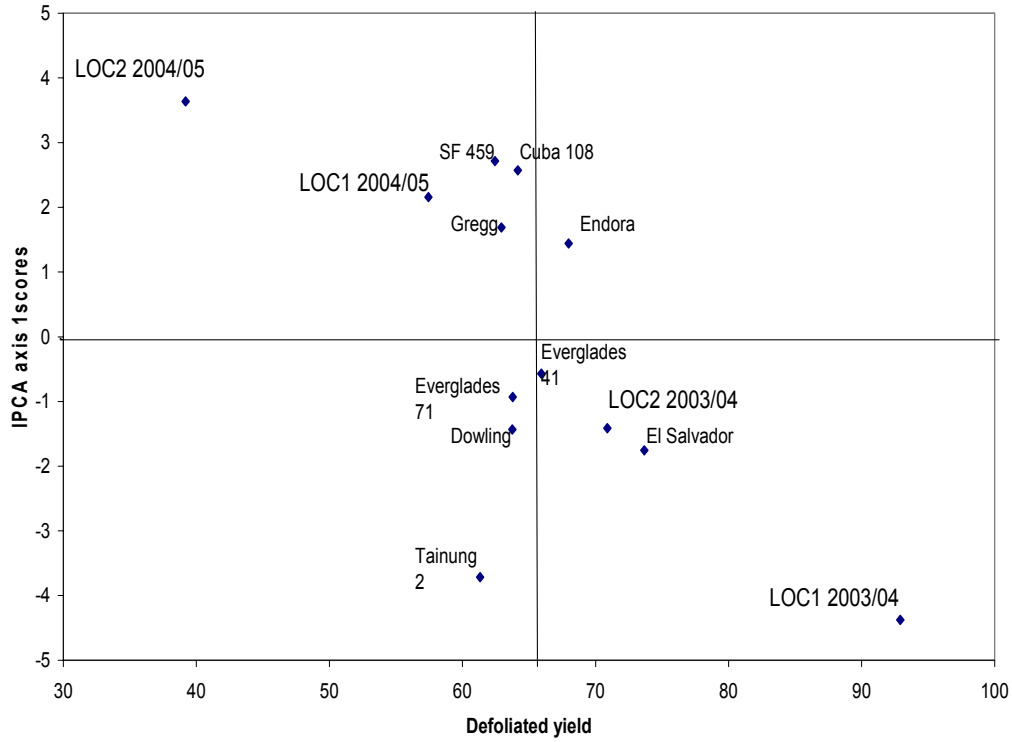

Fig. 4.5 AMMI biplot for defoliated yield means (t/ha) and IPCA 1 scores

The cultivar biplot is the mean defoliated yield value across different seasons of two locations

From the AMMI biplot for defoliated yield (Figure 4.5), when the IPCA 1 score and means were taken into account, the most stable genotype was Everglades 41 followed by Everglades 71, Dowling and El Salvador. Tainung 2 was indicated as the most unstable genotype in defoliated yield.

Dry stalk yield

For the dry yield, this analysis showed that environments and genotype x environment interaction were highly significant ($P<0.001$). The ANOVA table indicated that the G x E interaction was partitioned into three interaction principle component axis (IPCA). Only the IPCA 1 axes was significant and explained 80.29% of the total G x E interaction sums of squares percentage. The second IPCA (IPCA 2)

explained 15.59% of the total G x E interaction sums of squares percentage however it was not significant (Table 4.15).

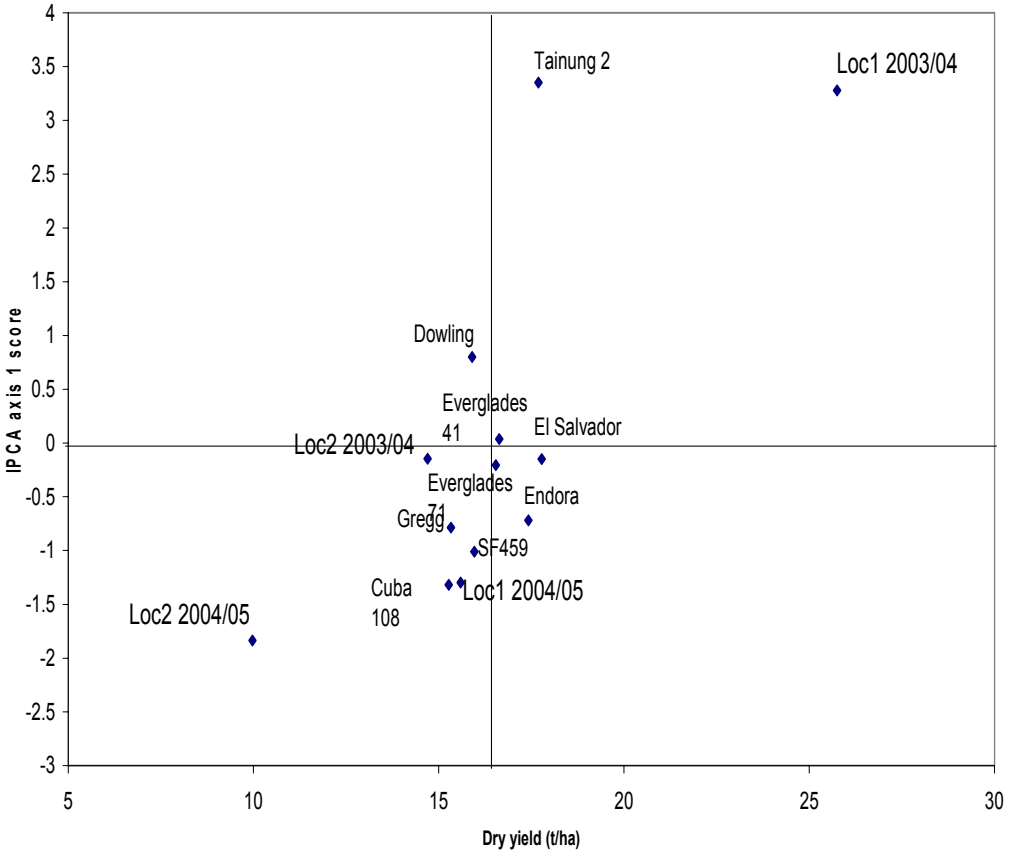

Fig. 4.6 AMMI biplot for dry yield means (t/ha) and IPCA 1 scores

The cultivar biplot is the mean dry yield value across different seasons of two locations

Fig 4.6 provided the AMMI biplot for dry yield. When the IPCA 1 score and means were taken into account, the most stable genotype was Everglades 41 followed by El Salvador and Everglades 71. Tainung 2 was the most unstable genotype.

Table 4.15.Analysis of variance of interaction in AMMI for the nine kenaf genotypes in 2003/04 and 2004/05 seasons

		Fresh yield (t/ha)		*Defoliated yield* (t/ha)		*Dry yield* (t/ha)	
Source	**df**	**SS**	**MS**	**SS**	**MS**	**SS**	**MS**
Total	143	131619		87336		8719.00	
Environments	3	82067.3	27356**	55323	18441**	4760.75	1586.9**
Reps within Env.	12	5500.20	458.35	3681.8	306.81	452.52	37.71
Genotype	8	3242.89	405.36	1807.1	225.89	119.47	14.93
Genotype x Env.	24	13791.8	574.66**	8137.9	339.08*	1247.64	51.99**
IPCA 1	10	10680.7	1068.08**	6096.4	609.64**	1001.16	100.17**
IPCA 2	8	2563.33	320.42	1760.9	220.11	194.53	24.32
IPCA 3	6	547.75	91.29	280.6	46.77	51.42	8.57
Residual	96	27017.6	281.43	18386	191.52	2138.71	22.28
Grand mean			80.85		65.11		16.50
R-squared			0.79		0.79		0.75
C.V %			20.75		21.26		28.60
IPCA1 %			77.44		74.91		80.29
IPCA2 %			18.59		21.64		15.59
IPCA3 %			3.97		3.45		4.12

*** P<0.01,* P<0.05*

e) Comparison of stability analyses

A comparison of the stability parameters for kenaf genotype traits was done for the different stability measures applied by using their rank levels. Results were listed in Table 4.16 (fresh yield), Table 4.17 (defoliated yield) and Table 4.18 (dry yield).

Wricke's (1962) ecovalence and Shukla (1972) gave the same stability ranking of the genotype (Table 4.16). Lin and Binns (1978) cultivar and AMMI's stability ranking were not different from them. On the overall rank, Everglades 41, El Salvador and Everglades 71 were the most stable genotype in fresh yield of nine kenaf genotypes. For defoliated yield, Everglades 41, Everglades 71 and El Salvador were indicated as the most stable cultivars of nine kenaf genotype (Table 4.17). El Salvador, Everglades 41, Dowling and Everglades 71 were regarded as the most stable genotypes in dry yield (Table 4.18).

In comparison with the mean yields for the three measured traits of assess genotype in the combined analysis (Table 4.9), El Salvador and Everglades 41 were the cultivars that tended to have the highest fiber yield in various environments.

Table 4.16 Summary of stability statistics of fresh yield from nine kenaf genotypes in 2003/04 and 2004/05 seasons

Genotype	*Cultivar superiority*		*Wi-Ecovalence*		*Shukla*		*AMMI*		*Overall Rank*
	Pi	R	Wi	R	Shukla	R	IPCA	R	R
Cuba 108	211.8	5	517.4	7	804.9	7	2.97	7	**7**
Dowling	229.9	7	278.5	4	395.3	4	-1.69	4	**4**
El Salvador	18.4	1	143.0	2	163.0	2	-1.58	3	**2**
Endora	140.9	3	368.1	6	549.0	6	1.81	6	**6**
Everglades41	99.4	2	59.6	1	20.1	1	-1.07	1	**1**
Everglades71	177.5	4	195.6	3	253.2	3	-1.22	2	**3**
Gregg	216.7	6	285.2	5	406.8	5	1.75	5	**5**
SF 459	294.0	9	673.7	8	1072.9	8	3.25	8	**8**
Tainung 2	299.7	8	926.8	9	1506.7	9	-4.23	9	**9**

Table 4.17 Summary of stability statistics of defoliated yield from nine kenaf genotypes in 2003/04 and 2004/05 seasons

Genotype	Cultivar superiority		*Wi-Ecovalence*		*Shukla*		*AMMI*		*Overall Rank*
	Pi	R	Wi	R	Shukla	R	IPCA	R	R
Cuba 108	138.7	7	297.9	7	462.2	7	2.57	7	**7**
Dowling	104.6	5	157.2	4	221.0	4	-1.43	3	**4**
El Salvador	13.6	1	126.3	3	168.1	3	-1.76	6	**3**
Endora	79.3	3	205.6	6	304.0	6	1.44	4	**5**
Everglades41	66.8	2	19.3	1	-15.4	1	-0.57	1	**1**
Everglades71	104.3	4	122.1	2	160.9	2	-0.93	2	**2**
Gregg	136.9	6	176.9	5	254.9	5	1.69	5	**6**
SF 459	179.4	9	380.9	8	604.5	8	2.71	8	**8**
Tainung 2	174.7	8	548.4	9	891.6	9	-3.72	9	**9**

Table 4.18 Summary of stability statistics of dry yield from nine kenaf genotypes in 2003/04 and 2004/05 seasons

Genotype	Cultivar superiority		*Wi-Ecovalence*		*Shukla*		*AMMI*		*Overall Rank*
	Pi	R	Wi	R	Shukla	R	IPCA	R	R
Cuba 108	44.61	9	30.75	7	45.29	7	-1.32	8	**9**
Dowling	21.51	3	11.56	3	12.39	3	0.80	6	**3**
El Salvador	18.75	2	1.79	2	-4.35	1	-0.15	2	**1**
Endora	27.79	5	18.94	6	25.04	6	-0.72	4	**5**
Everglades41	21.98	4	0.20	1	-7.09	2	0.04	1	**2**
Everglades71	28.59	6	18.34	4	24.02	4	-0.21	3	**4**
Gregg	37.32	8	18.64	5	24.53	5	-0.79	5	**6**
SF 459	36.56	7	33.80	8	50.51	8	-1.01	7	**8**
Tainung 2	13.72	1	177.9	9	297.53	9	3.35	9	**7**

4.3.3 Correlations between assessed traits

Correlations between six assessed traits for two years combined analysis were listed in Table 4.19. Highly significant ($P<0.001$) positive correlation was observed between fresh yield and defoliated yield, fresh yield and dry yield, fresh yield and middle diameter, fresh yield and basal diameter, defoliated yield and dry yield, defoliated yield and middle diameter, dry yield and middle diameter, basal diameter and middle diameter basal diameter and plant length. Significant ($P<0.005$) positive correlation occurred between defoliated yield and basal diameter, dry yield and basal diameter.

When the correlation is positively significant, this means these two traits would increase together. For example, in this study, highly significant positive correlation was observed between fresh yield and defoliated yield, it means when the fresh yield increased, the defoliated yield also increased.

Table 4.19 Correlations among the various traits of kenaf genotypes for 2003/04 and 2004/05 seasons

Traits	Fresh yield	Defol yield	Dry yield	Basal diameter	Middle diameter
Defol yield	0.9904**				
Dry yield	0.8915**	0.8934**			
Basal diameter	0.2939**	0.2640*	0.1979*		
Middle diameter	0.4467**	0.4149**	0.2884**	0.7498**	
Plant length	-0.0986	-0.1017	-0.0042	0.2848**	0.0486

* $p \leq 0.05$, ** $p \leq 0.01$

4.4 Conclusions and recommendations

In this study, nine kenaf genotypes were evaluated in two locations across two years. Highly significant differences were recorded between the locations and years for fresh yield, defoliated yield and dry yield. The yield values from Location 1 under irrigated conditions were higher than non-irrigated Location 2. The yield obtained in 2003/04 was significantly higher than that of 2004/05's. This was probably partly due to the later planting date in year 2, and the fact that replanting was done in year 1, but not in year 2.

Four different stability analysis parameters were used to analyse the nine kenaf genotypes for three yield characteristics. When compared the mean yields for the three measured traits in the combined analysis, El Salvador and Everglades 41 were the cultivars that tended to have the highest fiber yield in the two seasons and two locations.

From this study, it is recommended that kenaf should be planted under irrigation in the Winterton area. Adequate water will enable kenaf cultivar to perform better and improve their yield. It is also recommended that for kenaf production under dryland conditions in the Winterton area, cultivar Endora would be the most suitable, under irrigated conditions, El Salvador and Everglades 41 would be the best. The best cultivars with the highest stability across loclalities will be Salvador in this specific region in South Africa.

Chapter 5

Summary

Key words: Hibiscus cannabinus; combining ability; heterosis; genotype x environment interaction; stability; yield; South Africa

Kenaf (*Hibiscus cannabinus* L.) is an important fiber crop world wide, and has a great potential for its multipurpose uses. It could play a significant role in future fiber supply in Southern Africa.

Six diverse cultivars were selected from 14 genotypes as parental lines and crossed in a full-diallel method. The parental lines and 30 F1 hybrids were assessed and various traits were measured. General combining ability (GCA) was lower than specific combining ability (SCA). This indicated that non-additive genetic effects were more important for the inheritance of those characteristics. High heritability in the broad sense was recorded for the yield related characteristics (FPM, DPM, PH, BD, MD).

Heterosis was widely expressed in the F1 generation. Many crosses showed both mid-parent and high-parent heterosis for the yield characteristics (FPM, DPM, PH, BD, MD). It can be concluded that a hybrid breeding program could effectively improve kenaf yield.

Nine kenaf cultivars were evaluated for stability in two locations across two years. Highly significant differences were observed between the locations and years for fresh yield, defoliated yield and dry yield. The location under irrigated conditions had a higher yield value than under dry land conditions. Genotype x environment interaction was significant in this study.

Four different types of stability parameters and correlation analyses were used to evaluate kenaf cultivar stability. In the combined analysis, El Salvador and Everglades 41 were the cultivars that tended to have highest dry yield in the various environments. Tainung 2 was the most unstable cultivar for the measured characteristics.

Opsomming

Sleutelwoorde:: Hibiscus cannabinus; kombineervermoë, heterose; genotipe x omgewing interaksie; stabiliteit, opbrengs; Suid Afrika

Kenaf (*Hibiscus cannabinus* L.) is ‘n belangrike veselgewas wêreldwyd, en het groot potensiaal vir veelvuldige gebruike. Dit kan ‘n betekenisvolle rol speel in toekomstige veselvoorsiening in Suidelike Afrika.

Ses diverse cultivars is geselekteer uit 14 genotipes as ouerlyne en is gekruis in ‘n vol dialleel ontwerp. Die ouerlyne en die 30 F1 basters is geëvalueer vir verskillende eienskappe. Algemene kombineervermoë (GCA) was laer as spesifieke kombineervermoë (SCA). Dit het getoon dat nie-additiewe genetiese effekte belangriker was vir die oorerwing van hierdie eienskappe. Hoë breë sin oorerflikheid is gesien vir opbrengs en verwante eienskappe (FPM, DPM, PH, BD, MD).

Heterose is sterk uitgedruk in die F1 generasie. Baie kruise het beide mid- en hoogste ouer heterose getoon vir opbrengs en verwante eienskappe (FPM, DPM, PH, BD, MD). ‘n Kenaf basterteelprogram behoort baie effektief te wees om kenaf opbrengs te verhoog.

Nege kenaf cultivars is geëvalueer oor twee lokaliteite en twee seisoene. Hoogs betekenisvolle verskille is gesien tussen lokaliteite en seisoene vir vars opbrengs, ontblaarde opbrengs en droë opbrengs. Die besproeide lokaliteit het heelwat hoër nat opbrengs, ontblaarde opbrengs en droë opbrengs gegee. Daar was betekenisvolle genotipe x omgewings interaksie.

Vier verskillende soorte stabiliteitsanalises is gedoen, en korrelasies is bepaal. Uit die gekombineerde analise was El Salvador en Everglades 41 die cultivars wat die hoogste droë opbrengs gehad het in die verskillende omgewings. Tainung 2 was die mees onstabiele cultivar vir alle gemeette eienskappe.

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