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THESIS

PHENOLOGICAL CHARACTERISTICS AND FIBER PROPERTIES OF THAI HEMP (*Cannabis sativa* L.)

THITIVARA SENGLOUNG

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
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Thitivara Sengloung 2009: Phenological Characteristics and Fiber Properties of Thai Hemp (*Cannabis sativa* L.). Doctor of Philosophy (Botany), Major Field: Botany, Department of Botany. Thesis Advisor: Associate Professor Lily Kaveeta, Ph.D. 130 pages.

Hemp (*Cannabis sativa* L.) was cultivated under the Royal Initiative Project by Queen Sirikit Botanic Garden in 2002 to 2004. The phenological development of Thai hemp showed the stable flowering time over three years recorded. Thai hemp was dioecious, determinated at photoperiodism between 11 to12 hrs under natural climate in Chiang Mai province. Hemp root was diarch at primary stage and develop as ordinary dicotyledons at mature. The glandular and non-glandular trichomes appeared on leaf surface and female bract. There were 3 types of fiber in hemp stem, core fiber (20.23 µm width, 0.62 mm length) was in woody part, primary bast fiber (25 µm width) was irregular shape and secondary bast fiber (16 µm width, 3.4 mm length) was small and round shape.

The planting date had an affect to plant growth and development of Thai hemp. In 2004, hemp was grown in 4 sowing date which found that late planting dates have affect to reduce maximum stem length and diameter. The floral development and time for changing from vegetative to reproductive phase was faster. Male plant was higher in final stem length and the ratio of male: female plant was 57.68 : 42.32. The phyllotaxy of Thai hemp was changed from opposite decussate to spiral at 5.86 to 6.33 leaves pairs.

Fiber properties of Thai hemp which grown at density 20 to 30 plant.m^{-2} performed a good quality for modern spinning process. Fiber fineness was 14.5 to 26.6 $FBAI_{200}$ or 14.08 to 18.86 µm. Fiber collective strength was 10.9 to 27.4 cN.tex^{-1} and single bundle was 35.00 to 72.38 cN.tex^{-1}. Fiber bundle length between 22.0 to 28.4 mm, lignin content was 10.0 to 20.0 by Kappa number. Hemp yield the fiber content at 9.87 to 12.84%. The portion of defoliated stem was a wood 75.29 to 78.31% and bast 21.69 to 24.71%. Fiber maturity was reached at flowering time as the suitable time for harvesting. Testing methods, age of plant and various part of stem have an effect on fiber properties. The successful improvement should optimize the fiber quality and yield for specific utilization of hemp fiber.

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April, 2009

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LIST OF ABBREVIATIONS

µm	=	micrometer
ca	=	cambium
chl	=	chlorenchyma
co	=	cortex
ed	=	endodermis
ep	=	epidermis
gl	=	glandular trichome
lh	=	long hair
mm	=	millimeter
mx	=	metaxylem
MPa	=	mega Pascal
ngt	=	non glandular trichome
pa	=	parenchyma
pc	=	palisade cell
pd	=	periderm
pbf	=	primary bast fiber
ph	=	phloem
px	=	protoxylem
sc	=	spongy cell
sh	=	short hair
sp	=	secondary phloem
sbf	=	secondary bast fiber
st	=	stele
sto	=	stomata
sx	=	secondary xylem
twl	=	two wall layer
upe	=	upper epidermis
vb	=	vascular bundle
vc	=	vascular cambium
vs	=	vessel

LIST OF ABBREVIATIONS (Continued)

xy	=	xylem
otw	=	outer wall
inw	=	inner wall

PHENOLOGICAL CHARACTERISTICS AND FIBER PROPERTIES OF THAI HEMP (*Cannabis sativa* L.)

INTRODUCTION

Hemp (*Cannabis sativa* L.) bast fiber was used for textile and cordage more than 4000 years. It is widely cultivated throughout the temperate region from Europe to North America more than tropical Asia (Phengklai, 1981; Lu and Clarke, 1995; Nakamura, 2000). In European countries, hemp was cultivated for special pulps, cellulose composite, renewable insulation material and automotive industry (Linger *et al*, 2002; Karus *et al*., 2003; Karus, 2004). In China, hemp was one of the earliest crop in ancient Chinese literature. They use hemp plant for many different purposes. But fiber of male plant was used to spin yarn and weave cloth. Until now, China is currently the world leader in hemp production and hemp cloth (Lu and Clarke, 1995).

In Thailand, hemp was used by the hill tribes called Hmong, who live in the North of country (Deepadung, 1995). The information about their fiber is still limited and used traditional technology in the process. Their pure hemp fabric was coarsed and sold only in local market in small row approximately 50 cm of width. The material may import from China, Myanmar and Laos where across the Thai border and some are obtained from the hill tribes. The utilization of pure hemp cloth in commercial is used for handbags and others decorative stuff. High quality of fabric made from hemp spun with cotton was imported from China with high price.

Hemp cultivation is harmless to environment with little interference accumulation or emission of chemical inputs (Struik *et al*., 2000). It has been reported that hemp is short day plant and there was high effecting of both genetic and climate to fiber quality (Kozlowski and Pallardy, 1997). For the production of textiles and high-tech composites, fiber characteristics such as strength, length, diameter, chemistry, and homogeneity are influenced considerably by harvesting time (Mediavilla *et al*., 2001). Thai hemp variety which Hmong grown never been studied. Therefore, the basic information of growth, development and adaptation on fiber characters of Thai hemp cultivated under natural condition are needed to be investigated. The information of hemp phenology and its fibers was revealed and the knowledge obtained is essential for improving the species as a potential economic plant and a criteria information for considering to allow growing hemp.

OBJECTIVES

1. To determine the phenology of hemp under Thai climates.
2. To determine stem anatomy and stem fiber.
3. To determine the effect of sowing dates on growth and development of hemp.
4. To determine fiber properties of Thai hemp.

LITERATURE REVIEW

1. Botanical characteristics

Cannabis sativa L. has common names as: asa, hakuso, nokyuma (Japan); Kancha (India, Thailand); marijuana, hemp, industrial hemp, indian hemp (Europe); chanvre (France); canapa (Italy); canamo (Spain); hanf (German). In Thailand, all *Cannabis* was called normally as Kancha. But in the meaning of marijuana (Cannabis for drug production) and hemp (Cannabis for fiber production) in English, were called marijuana as Kancha and hemp as Kanchong. This crop has been cultivated very long time ago along with flax. The habitat's origin was said to be around India and Prussia (now Iran). At present, it is widely cultivated throughout in the temperate regions from Europe to North America more than tropical Asia (Phengklai, 1981; Nakamura, 2000; The Botanical Garden Organization, 2000; Anonymous, 2003)

The botanical characteristics of *Cannabis sativa* L. are described as tall erect herb up to 6 m height with robust stem. Hemp is dioecious or monoecious plant, all parts viscid pubescent. Stem is slightly angulate. Leaves orient opposite and digitate with 5 to 7 foliolates. Foliolates are dentate or serrate leaves. Leaves arrange in spiral upward. Upper surface scabrid with short, stiff hairs with cystoliths, and pubescent with appressed hair on the under surface, apex acuminate to caudate, base narrowly cuneate, nerves 8 to 20 pairs, reticulate vein inconspicuous. The staminate flowers are grouped in axillary or terminal panicle with few leaves. Tapals 5 finely pubescent, stamen 5, anther dehescing by an apical pore. Female flowers solitary at axil and terminally arrange in spike. Each flower enveloped by a membranous spathe-like, dark green bract with glandular hair, perianth absent, ovary 1-locular, style short divided into 2 long stigmatic arms with 1 ovule. Fruit is achene, smooth, shining, yellowish or brownish, ovoid or ellipsiod. Seed with fleshy endosperm (Phengklai, 1981; Hatton, 1999; Promratrak, 2002).

Under the microscope, both surfaces of leaf are covered with many smooth and curved unicellular trichomes. Some cystoliths are enlarged at the base, due to the presence of calcium carbonate crystals (cystoliths). It overlaps one another like fish scales. Glandular trichomes are rare on the leaves, but not on the pistillate inflorescence bracteoles where hairs are with multicellular multiseriate stalks often separated from their globose heads which consists of 8 to 16 cell (Hatton, 1999).

2. Varieties

Although it had been thought for a long time that *C. sativa* L. species comprised of at least two varieties, it is known that in fact hemp adapts to almost all ecological conditions. The plant genotype is also an important determine factor. Hatton (1999) has defined three types of hemp based on the concentrations of Δ^9-tetrahydrocannabinol (pharmacologically active Δ^9-THC, commonly referred to as THC), and cannabidiol (=CBD, inactive compound, but a good identification marker):

2.1 The "drug" (resin) type with high THC concentration (>1%) and no CBD; this type of composition is observed in all of the hemp growing in warm climates, and producing abundant resin.

2.2 The "hemp" (fiber) type with very low THC concentration (<0.3% and in fact <0.1% for the majority of the "textile" varieties cultivated in northern temperate climates) and high CBD concentration.

2.3 The "intermediate" type, with high concentrations of both THC and CBD; this type is characteristic of hemp from the Mediterranean region.

3. Utilization of hemp

Hemp fiber get glued together mutually and form the external appearance, they form long fibers reaching up to the length of 2-3 meters. The color is pale yellow, silver-ash, pale green etc. The moisture absorption is slightly more than flax and cotton. It is hard with poor flexibility (Nakamura, 2000).

Hemp has a wide range of potential uses. Bast fibers traditionally have been used for textile, rope and twine (Sankari, 2000). For long fiber uses (e.g. textiles and composites), the stem value depends primarily on the proportion of bast fibers. It is commonly known that a high bark yield and bast fiber content as well as a low secondary bast fiber content are advantageous for the production of textile (Mediavilla *et al*., 2001). Yield of hemp being a raw material for textile and codage. Either the woody core or the bark of the stem are role as potential raw material for paper pulp. Therefore, the economic yield of a hemp crop is defined as the yield of stem dry matter (de Meijer and Keizer, 1994). For the textile industry, the primary bast fiber is valuable long fiber and the secondary bast fiber is less valuable tow (Hoffmann, 1961).

Hemp yields large quantities of useful cellulose, which used as a raw-material and are a non-toxic, harmless, biodegradable and recyclable. (Struik *et al*., 2000; Vehviläinen, 2002). In Europe, hemp is used in automotive industry as fiber composite (Müssig *et al*., 2005) and cultivate hemp for decontaminate heavy metal polluted soils or termed phytoremediation (Linger *et al*., 2002).

4. Hemp phenology

Phenology is the study of the effects of climate on the seasonal occurrence of flora such as date of flowering and the periodically changing form of plant, especially the affects of its relationship with the surrounding environments (Allaby, 1992). The major biotic factors influence to phenology are temperature and photoperiod. Hence, phenology can be described quantitatively in terms of development units required to complete the life cycle, or a phase or sub-phase of the development.

Plant phenology is the occurrence and changed form of plant which related to their age and environment. According to Mediavilla *et al.* (1998) (Table 1), the stage of germination and emergence was recorded only cotyledon unfolded day. At vegetative stage, a leaf was considered as unfolded when leaflets are at least one centimeter long.

Table 1 Definitions and codes of growth stage of *Cannabis sativa* L. according to Mediavilla *et al*. (1998)

Code		Definition
Germination and emergence		
0000	Dry seed	
0001	Radicle apparent	
0002	Emergence of hypocotyl	
0003	Cotyledons unfolded	
Vegetative stage refers to main stem. Leaves are considered as unfolded when leaflets are at least one cm long.		
1002	1st leaf pair	1 leaflet
1004	2nd leaf pair	3 leaflets
1006	3rd leaf pair	5 leaflets
1008	4th leaf pair	7 leaflets
1010	5th leaf pair	
10xx	11th leaf pair	xx = n(nth leaf pair)
Flowering and seed formation refers to the main stem including branches.		
2000	GV point	Change of phylotaxis on the main stem from opposite to alternate. Distance between petioles of alternate leaves at least 0.5 cm.
2001	Flowering primordia	Sex nearly indistinguishable
	male	
2100	Flowering formation	First closed staminate flowers
2101	Beginning of flowering	First opened staminate flowers
2102	Flowering	50% opened staminate flowers
2103	End of flowering	95% of staminate flower open or withered
	female	
2200	Flower formation	First pistillate flowers. Bract with no styles.
2201	Beginning of flowering	Styles on first female flowers
2202	Flowering	50% of bracts formed
2203	Beginning of seed maturity	First seed hard
2204	Seed maturity	50% of seeds hard
2205	End of seed maturity	95% of seeds hard or shattered
	Senescence	
3001	Leaf desiccation	Leaves dry
3002	Stem desiccation	Leaves dropped
3003	Stem decomposition	Bast fiber free

Record leaves appearance rate and the number of leaflets while phylotaxis is opposite. At flowering and seed formation was consider since changing of phylotaxis on the main stem from opposite to spiral and the distance between petioles of spiral leaves at least 0.5 cm. Record node number that phyllotaxis changed. When sex nearly indistinguishable, growth stage is consider to flowering primordial. Between male and female plant, flowering formation is recognized when first close staminate or pistillate flower appear. Beginning of flowering is first opened staminate or style on first female flowers. Flowering is 50% opened staminated flowers or 50% pistillate bracts formed, when 95% of the staminated flower open it was consider to be the end of flowering. In female plant, first seed hard is the beginning of seed maturity and when 50% of seed hard is seed maturity. Senescence stage was started from leaves turn dry and drop.

Before flower initiation take place, some vegetative growth must have occurred. At least this is no more than the number of leaf primordia present in the seed. Minimum leaf number has been determined for several different species of plants. The concept of minimum leaf number is close to, but not exactly the same as, the concept of juvenility. The minimum leaf number is the least number of leaves that must formed before floral initiation (Vince-Prue, 1975).

It has been found that the flowering stage of *Cannabis* is induced by short days and genetic controlled, the actual time of floral initiation is modified by weather, site conditions, and management practices. Hence, the time of floral initiation varies somewhat from year to year and also in different parts of the natural range of a species (Kozlowski and Pallardy, 1997; Lissen and Mendham, 2000; Lissen *et al*., 2000a; Lissen *et al*., 2000c).

At onset of flowering, both number of nodes with opposite phyllotaxis and the number of nodes with alternated phyllotaxis decreased with initial plant density (van der Weft *et al*., 1995). In contrast, yield of inflorescence and of dead leaves decreased with increasing initial density. Plant slenderness (height/weight ratio) increased with initial density. Solubility of bark increased with initial plant density. The increase of the proportion of stem in the above ground dry matter with initial plant density was another result of increased stem growth caused by inter-plant competition of which called self-thinning.

Hemp phenology studied by Lissen *et al*. (2000b) in 2 varieties of hemp confirmed a quantitative short day plant need base vegetative period 383 and 390 °Cd at photoperiods less than about 14 hrs. At longer photoperiods, flowering was progressively delayed. Thus, effect of temperature on the flowering response is accounted by the use of thermal time as a measure of phenology.

The variation of *Cannabis* in phenological development and in stem elongation studied by de Meijer and Keizer (1994), found large variation for the day of anthesis and the day of seed maturity. The critical photoperiod for induction of flowering increases with altitude of adaptation. Many authors describe changes in phenological development when adapted populations are moved to other latitudes.

The studied of the effect of temperature on leaf appearance and canopy of hemp by van der Werf *et al*. (1995b) found the rates of leaf appearance and stem height rate increased linearly with temperature between 10 ºC and 28 ºC. The base temperature for leaf appearance was 5.7 ºC from the growth chamber experiments and 1 ºC from the field experiments. Thermal time is a simple and accurate tool to describe leaf appearance and light interception in fiber hemp. In addition, the radiation use efficiency changed during development which is low after flowering (Struik *et al*., 2000).

In sunn hemp (*Crotalaria juncea* L.), which is short-day flowering species was concluded by Cook *et al*. (1998). The planting date may effect on stalk yields because delay in planting was shorthorn the growing season. It is therefore important to find the optimal harvest time, i.e. growth stage for obtaining mature fibers of optimized quality with an amount of lignin as small as possible (Keller *et al*., 2001).

5. Anatomy of hemp stem and bast fiber

Transverse cross section of hemp stem shows outer most part is cuticle or periderm in secondary growth stage. Epidermis is placed beneath the cuticle. Large number of trichomes are greater in female than male plant. Bast fiber or pericyclic fiber is phloem fiber, which had thickening wall that easily stained with fast green. In female plant, pericyclic fiber is smaller and thinner than in male plant. There are cambium cells arrange between phloem at the outside and xylem inside. Woody core is usually as same as typical woody plant. There are parenchyma cell, xylem fiber, and vessel. Pith is parenchyma at the middle of section and may have rosette crystal (Hayward, 1984; Garcia-Jaldon *et al*., 1998; Promratrak, 2002)

Hemp contains three different kinds of fibers. There are core fiber, primary bast fiber and secondary bast fiber. Core fibers are located inside the vascular cambium averaging 0.5-0.6 mm long. Bast fiber consists of primary bast fiber and secondary bast fibers, which according to Hoffmann (1961) differ in length of single fiber cells, cell wall is thickness, strength and stage of lignification. Primary bast fiber is situated outside the vascular cambium. It develops during the phase of rapid stem elongation and consists of large and long fiber cells averaging 20 mm in length. Secondary bast fibers rise from the prodesmogen, more lignified and shorter, averaging just 2 mm in length (van der Werf *et al*., 1994).

6. Influence of growth stage to fiber quality

Hemp is an annual plant which produces pericyclic fibers. Green fibers from harvested plants comprise cellulose (55%), hemicellulose (16%), pectic substances (18%) and lignin (4%). The fiber cells which are bounded by the middle lamellae, are arranged in bundles of which are themselves separated by parenchyma cells of the cortex, the latter having pectic and hemicellulosic rich in cell walls, and the woody core thickening with lignified cells (Garcia-Jaldon *et al*., 1998).

Bast fiber is arranged in bundles in the bark of the stem. Therefore, the industrial use of hemp required the separation of the fibers from the whole plant (Keller *et al*., 2001). The bast fiber content in hemp stem was reported to depend on genotype, plant density and development stage of the hemp at harvest (Höppner and Menge-Hartmann, 1994; van der Werf *et al*., 1994; Cromack, 1998). Approximate 54% of the fibers were located in the bottom part, 34% in the middle and only 12% in the top part of the stem. After flowering, fiber yield decreased in the whole stem (Mediavilla *et al*., 2001).

Wood is made up largely of cellulose, lignin, and hemicellulose in various proportions. The quality of the cellulose was relatively stable over the growing season, but lignification may proceed rapidly sometime after flowering (Struik *et al*., 2000). Lignin is distributed throughout the secondary wall and compound middle lamella, but the greatest concentration is in the middle lamella. The secondary wall constitutes a large proportion of the total cell wall lignin is located in this region. The distribution of hemicellulose parallels that of lignin within the wall. Hemicelluloses surround the cellulose microfibrils and occupy space between fibrils. Crystalline and amorphous forms of cellulose occur within the cell wall. Cellulose molecules form microfibrils, and these form fibrils (Eriksson *et al*., 1990).

The process of bark fiber formation is complex and also strongly related with the growth pattern of the plant (Mediavilla *et al*., 2001). During the vegetative phase, primary fibers were created first and then filled. In the middle of the stems, only primary fibers could be identified. The peak of the stem and fiber yield at the male plants flowering stage was probably caused by an increase in production and lead to a filling of secondary fibers. After that, and because of their characteristics, secondary fibers may cause a decrease in bark quality. Stem, bark, and fiber yield reached their maximum at the flowering peak of flowering of male plants which called technical maturity. Technical maturity coincides with the time when most of the staminate flowers on male plants are open and occurs usually at the beginning of the bract formation of female plants (Bòcsa and Karus, 1997).

During the season of growth, primary fibers in the middle of the stem showed different degrees of ripeness. At the 6th leaf pair stage, 81% of all fibers were almost empty. Two weeks later, at the 8th leaf pair stage, the beginning of the fiber filling process could be recorded. At the flowering induction, secondary fibers appeared in the bark and commanded up to 45% of the fiber area. In contrast to male plants, after the change of phyllotaxis on the main stem from opposite to alternate, the female plants showed as abrupt increase in secondary fibers. Subsequently, no significant differences between male and female plants could be determined (Mediavilla *et al*., 2001).

7. Hemp fiber properties

Properties of fiber come from chemical component in cell of fiber that related to physical properties which different within and among species of fiber plant. The properties of fibers are commonly viewed as important, when these fibers are used as raw material in fibrous good. Some natural fibers of non-wood plants, such as hemp, flex, kenaf, can be used in several industrial fields (textile, paper, composite materials). Each of these fields sets specific standards for assessing the properties of raw materials, according to the final use of the products. For example in the textile sector, the quality of a clothing fabric cannot be assessed with the same criteria applied to tapestry, house linen, or high-tech fabrics. Furthermore even within the clothing market a distinction has to be made among the different targeted segments. However, in most cases the best qualities are those that can be spun into the finest yarns (Nakamura, 2000; Bonatti *et al*., 2004; Udomkichdecha, 2005).

7.1 Chemical properties

Cellulose is main composition of plant natural fiber, followed by hemicellulose, lignin, pectin, and other substances. Long chain of cellulose molecule and high molecular weight was effect to properties of fiber as well. Hemicellulose is a branched chain molecular that affected to inner structure of fiber as crystalline and amorphous region. These molecular structures have the influence to fiber properties of each fiber. The chemical compositions of hemp fiber are 75 % cellulose, 9.5 % pectin/lignin, 10 % hygroscopic water, 2.1 % water soluble substances and other 2 % (Table 2). The physical characters can describe as diameter 15-50 µm, length 1,500-5,000 mm and tenacity 40-70 N/tex (Sponner *et al*., 2005).

7.2 Physical properties

Physical properties of hemp fiber were 10-30 µm width, strength 60-83 kg.mm^{-2}, elongation 1.8%, specific gravity 1.28 – 1.48 and moisture content 12%. The fiber characteristic of hemp closes to flax (Table 3). The following properties are aim to purpose of spinning process. Most physical properties are (Nakamura, 2000).

7.2.1 Fiber length

There are limitations in the length of natural fiber. When fibers are converted into thread or yarn after putting them through a complicated spinning process and making continuous assembly of single fibers. Long fibers like hemp are cut at suitable length then they are put through spinning process.

7.2.2 Fiber fineness

The thickness of fiber can be known from its width, diameter and sectional area. But, there are very few fibers, which have a completely round sectional area, so it is difficult to get the perfect answer. Therefore, there is a number, which shows the ratio of length against a fixed weight. For example, fineness is indicated by Denier (D) or yarn count (refer to "yarn varieties" section). But, strictly specking, if the measurement of specific gravity of the fiber is different in this method, outward thickness changes even in the fibers have the same denier Ω count. Normally, mm or micron is used as the unit, while showing the width or diameter and mm square or micron is used to show the sectional area.

The excellence of fiber quality is evaluated from its fineness and its usage cost is higher accordingly. A fine, high level yarn can be prepared only if there is fine fiber. Again, in case of thick yarn too, instead of using a small quantity of thick fiber, it is better to use many fine fibers together. The yarn made in this way has a smooth appearance and it is also flexible to handle.

7.2.3 Strength and elongation

The strength and elongation of a fiber are very important factors in the use of fiber. The durability of fiber goods varies according to its formation and method of constitution etc. But, it also varies according to the degree of strength and elongation of the fiber used under the same status. The strength involves the force, which withstands dynamic external force, such as tensile strength, bending strength and friction strength and the force, which withstands the weathering and weakening due to ultra-violet rays, temperature and humidity, chemicals etc. The durability of a yarn or fabric is decided after analyzing all these, Out of these, the strength, which withstands tension, is the most important one. Since it is easy to measure the tensile strength (also called as pulling strength), usually the strength of a fiber is expressed as tensile strength. The ratio of length stretched till the fiber is broken. The unit of tensile strength is usually shown by g count per one fiber, g count per 1 denier and kg count per unit area.

7.2.4 Young's modulus

The pulling strength (same value as the tensile strength) per unit sectional area at the time of stretching up to the maximum limit of returning to the original length, it took as the coefficient showing the elasticity of that fiber. This is called as Young's modulus and usually it is shown with kg count per 1 square mm or per 1D. In single fiber, the size of Young's modulus doesn't differ much while showing the fiber hardness. However, in the yarn and fabrics, Young's modulus varies according to the strands of yarn, bulk, fabric formation, density, and thickness apart from the fiber hardness.

Other fiber physical properties such as specific gravity, hygroscopic property, thermal conductivity, spinning property, fragility etc. were measured according to the specific propose of fiber utilization which needs a different value of each characteristic of fibrous goods.

Table 2 Chemical and physical properties of hemp fiber (Sponner *et al*., 2005).

The chemical constituents of hemp fiber		The physical characteristics of hemp fiber	
Pectin/ lignin	9.5 %	Diameter	15 – 50 micron
Water soluble substances	2.1 %	Length	1500-5000 mm
Vegetable wax and fat	0.6 %	Tenacity	40 – 70 N/Tex
Mineral matter	0.8 %	Elongation at breaks	23 %
Hygroscopic water	10.0 %	Regain	12 %
Cellulose	75.0 %		
Other	2.0 %		
	100.0 %		

Table 3 Physical properties of natural fiber (Applied from Nakamura, 2000).

Kind	Width	Strength and elongation		Specific	Moisture content
	(μ)	Strength	Elongation	gravity	Official regain
		Kg/mm^2	%		%
Silk	18-30	44.8	20-25	1.30-1.37	11
Raw cotton	12-28	37.6	7-9	1.47-1.52	8 1/2
Flax	8-25	80-92	1.5-2.0	1.46-1.52	12
Ramie	25-50	70-80	2.3	1.48-1.52	-
Hemp	10-30	60-83	1.8	1.28-1.48	12
Jute	6-26	41-44	1.3-1.4	1.44-1.48	13 3/4
Manila hemp	10-20	-	-	1.32-1.45	-

MATERIALS AND METHODS

Materials

1. Thai hemp seed was supplied by Queen Sirikit Botanic Garden

2. Microscope

    ZEISS Axioskop2 plus - HAL100

    Sterio microscope - Olympus SZ3060

    Light compound microscope - Olympus CH30/SZ30/SZ-ST

    Scanning Electron Microscope (SEM) – Jeol JSM 5600 LV

3. Equipment for plant microtechnique such as micrometer, microtome, slide, cover slip

4. Equipment for SEM

    Critical point dryer – Hitachi HPC-2

    Ion Coater – Eiko Engineering IB-2

5. Equipment for fiber analysis

    Course separator – Self development Faserinstitut Bremen

    Almeter - AL100

    Diastron – LSM500- DIA-STRON Ltd, UK

    Airflow - FMT-Shirley device

    Optical Fiber Diameter Analyzer (OFDA)

6. Chemical agents for plant microtechnique

    Ethanol – K36476983 MERCK

    Xylenes – UN No.1307 B/No. HoC172 UNIVAR

    Paraplast No.8889-501007 - Sherwood

    Safranin O

    Fast green

    Ether

    Butanols (TBA) BA UN No.112 – UNIVAR

    Acetone UN1090 / MERCK

7. Chemical agents for fiber maceration

    Chromic acid

Nitric acid

Hydrogenperoxide

Acetic acid

Sodium hydroxide - UN1823 B888598 630 - MERCK

8. Chemical agents for SEM

Glutaraldehyde

Phosphate buffer

Osmiumtetroxide

9. Measuring tape, vernia caliper

10. Fertilizer 16-16-16 and 36-0-0

11. Chemical agents for lignin analysis

0.1 N $KMnO_4$, 4 N H_2SO_4 , 1 N KJ-solution, 0.1 N $Na_2S_2O_3$

Methods

1. Planting location and climate

Planting location was established in Chiang Mai province, Northern Thailand. Three locations of hill area under Queen Sirikit Botanic Garden (QSBG) project were selected. There were Doi Baelae, Sob-Kong District, Amphor Omkoy; QSBG, Amphor Mae Rim and Huay Mae-Kieng high land agricultural station, Muang Na District, Amphor Chiang Dao. Soil was collected from each planting site for the analysis of texture, pH and nutrition. Meteorological record of minimum, maximum, average temperature, rainfall, relative humidity and daylength were recorded from 2002 to 2004.

2. Preliminary study on hemp plant

2.1 Plant material, botanical and agronomical characteristics

Hemp seed in all experiments were supplied by QSBG, Chiang Mai province from traditional used. Hemp plantation under Royal Initiative Project in 2002 was carried on Doi Baelae, Amphor Omkoy, Chiang Mai province. Two sowing date were set on July 28th and October 14th in 2002 as the first experiment. Morphological of hemp stem, leaf, flower and seed were described. Height and diameter at 10 cm height (D_{10}) were measured on December 15th in the same year.

2.2 Anatomical study

Hemp mature plant from Doi Baelae was selected and divided into 3 part as top, middle, bottom by the total height of plant. Each part were cut the middle section as a specimen. Then fixed separately in 50 % FAA solution for at least 24 hrs., dehydrated with an ethanol tert-butyl alcohol series and finally embedded in paraffin (John, 1958). Cross-sectioned tissues were prepared by rotary microtome at 15-30 μm, then stain and counterstained with safranin and fast green. Three microscopic photographs of cross-sectioned stem were done by ZEISS Axioskop 2 plus camera. The anatomical structure of root and leaf were investigated as same method as plant microtechnique.

2.3 Fiber morphology

The hemp stem from 2.1 was used for fiber study. Each part of stem was decorticated by hand. Core was macerated by Jeffrey's method. Maceration fluid consists of equal volumes of 10% chromic acid and 10% nitric acid treated for 2 days at 40 °C, then washed and shaked with glass beads (Jeffrey, 1917; Franklin, 1945; John, 1958). They were stained with safranin (water base solution), then dropped on slide and covered with cover glass. Bast fiber was macerated by Franklin's method. The fluid consists of equal volumes of hydrogen peroxide and acetic acid treated for 5 days at 40 ºC, then fiber length and width of 100 fibers per sample were measured.

3. Effects of sowing date on growth and development of hemp

3.1 Plant material and cultural method

Thai Hemp was planted at 10 x 20 cm space in May and July 2003 and repeated in May, July and September 2004. Hemp seed was over sowed at 5 seed.pit^{-1} and hand removed to 3 plants pit^{-1} after germination. Ground soil was applied furadan (carbofuran) if necessary and sprays lannate (methomyl) for protecting seed from an insect. For each planting date, hemp was fertilized with 16-16-16 NPK at 10 days after planting and 36-0-0 NPK at 45 and 90 days after planting. For the late sowing date, the fertilization was applied upon the need of plant. Weeds were manually eradicated before and at 30 days after planting.

3.2 Plant growth and development

Planted hemp in 2003 was established in Huay Mae-Kieng high land agricultural station. Height and D_{10} were randomly marked and recorded for 40 plant at monthly interval in each sowing date. The season ended on a time of flowering and seed appearance.

In 2004, hemp planting area was established at QSBG. Four sowing dates were set up in July, August, September and October. Plant growth and more details on number of leaves appearance and phyllotaxis change were investigated in this treatment. Each sowing date plant was randomly marked for 10 plants.

4. Hemp floral development

4.1 Plant material and cultural method

Hemp grown in 2004 at QSBG were used as resources plant for this experiment.

4.2 Individual floral development

When plant was on vegetative stage and unable to identified sex, morphology record was carried out by photograph weekly interval. After morphology chance on bud and floral development, selected flower were labeled and observed by photograph every stage of development of each 3 days. Ten plants on hemp sowing date 1 and 2 were set for this experiment. Both male and female plant was carried out by chance of the selected plant.

4.3 Field floral development

The stage of vegetative growth and reproductive growth of 4 sowing date were recorded according to the abbreviation in Table 5. The flowering time was recorded according to the time of changing phyllotaxis on the main stem from opposite to spiral, flower formation, beginning of flowering, end of flowering, seed set and seed maturity of each sowing date.

5. Fiber properties

5.1 Plant material

Hemp was grown at Huay Mae-Kieng high land agricultural station where located at Chiang Dao, Chiang Mai province. Hemp was sown, on July 10th 2004, on sloping and flat areas. In September, there was heavy rain and the mountain flooded in the planting area. Only the field on the hill above the flood was remained. On September 15th while the hemp was 65 days old, the first hemp was harvested (harvest 1) while sex was indistinguishable. After pollination and sex had been identified, the second harvest (harvest 2) was investigated on November 10th, 2004, when hemp was 120 days old.

5.2 Harvesting method and fiber decortication

Harvest time occurred during the rainy season with high humidity, so fungi could easily contaminate fresh stems. To avoid this problem, fresh decortication was chosen to reduce fiber damage and convenient for fiber harvesting and management. In harvest 1, fresh and dry decortications were applied to evaluate decortication method. Fresh decortication was decorticate fresh stem. Conversely to dry decortication that applied to dried stem.

Each harvested hemp stem was separated into top, middle and bottom parts. Which divided into 3 equal length from the total length of stem. After fresh decortication each sample were dried naturally. Harvest 1 was a stage of vegetative growth while harvest 2 was a stage of early male pollination. Each treatment contained 5 replications, each replication was a square meter area. The number of plant in each replication were counted and subdivided into male and female group. All decortication was performed by hand.

5.3 Chemical and mechanical separation

All bast fiber was separated with chemical preparation method from Bredemann (1942) by 2% NaOH in an autoclave at 0.2 MPa pressure. Bast was put in the cab bottom with the solution. After treatment, separated fibers were rinsed with tap water and dried in an oven at 105 °C for 1 hr. Then the mechanical separation was applied to the sample. From each fiber sample, a handmade sliver was taken with a mass of 6 $g.m^{-1}$. The parallelised fiber-bundles were refined with a coarse separator. A self-developed laboratory coarse separator was used. This machine consists of a serrated cylinder (Ø 261 mm) and fed by a rotating roll (Ø 32 mm). The distance from the feeding roll to the rotating serrated cylinder is 20 mm. The fiber transport after coarse separation was organised by air. The separation achieved was compared with industrial separation techniques (Müssig, 2001).

5.4 Fiber testing condition

The fiber was conditioned and assessed in the standard atmosphere for testing textiles (Anonymous, 1974) at an atmosphere of 65% relative humidity and a temperature of 20 °C were applied before testing 24 hrs and during testing procedure. Fiber testing was investigated in fiber fineness, fiber strength, fiber length distribution, lignin content and maturation of fiber.

5.5 Fiber fineness analysis

5.5.1 Fiber fineness by Airflow method

Airflow method was developed to measure fineness of wool fiber. Airflow method does not provide information about the distribution of fineness for individual fibers or bundles. However, this method is very rapid as well as being highly reproducible (Drieling *et al*., 1999). The pressure of the Airflow testing device was adjusted to a water column of 120 mm and calibrated after a recently developed method to get comparable Airflow values from different labs and researchers for

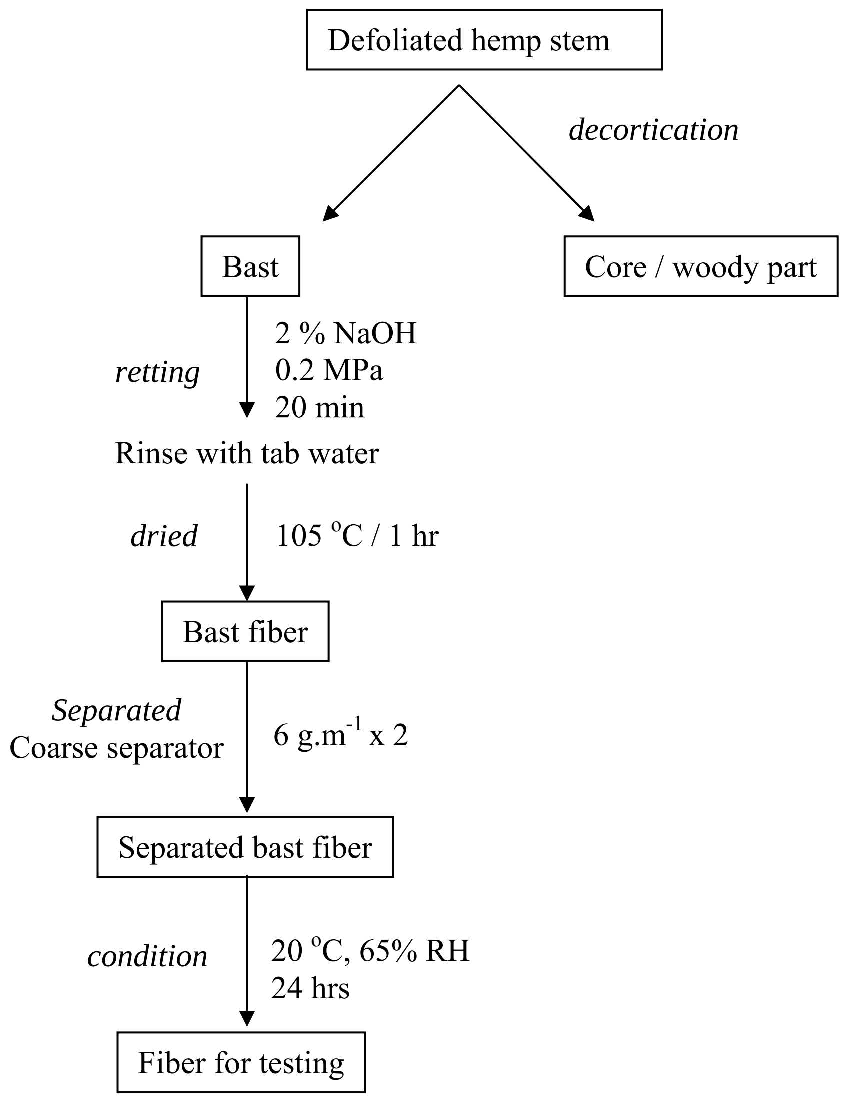


Figure 1 Chart of hemp fiber preparation for testing fiber properties.

hemp testing (Müssig, 2001). For each sample, three specimens were used, each weighing 2.5 g. The measurement was taken three times.

5.5.2 Optical Fiber Diameter Analysis method

The fineness of fiber bundles was examined by an Optical Fiber Fineness Analyser (OFDA), which was developed for measuring the diameter of wool fiber (Baxter *et al*., 1992). This apparatus efficiently measures width distribution of bast fiber bundles (Drieling *et al*., 1999; Müssig and Martens, 2003). For the examination of the bundle width distribution with the OFDA, the bundles were cut into 3 mm long snippets. The snippets were prepared by tweezers on a slide. For each hemp sample, 3 slides were prepared, each slide was scanned two times and the results were averaged.

5.6 Fiber strength analysis

5.6.1 Stelometer method

The fiber strength was measured on hemp fiber bundle collectives by a Stelometer (Müssig and Martens, 2003). Samples were clamped in a Pressley clamp with plexiglas jaws at a gauge length of 3.2 mm. The Stelometer was calibrated according to ASTM D 1445. To obtain a representative set of results, more than 20 collectives were tested. The strength of hemp fiber bundle collectives in cN/tex can be calculated from the breaking mass of the bundle collective (kg) divided by the mass-related fineness of the tested collective (tex). The mass of the collective was measured with an accuracy of 0.01 mg.

5.6.2 Diastron method

For testing the tensile properties of single elements, instead of the strength of collectives of elements (measured with a Stelometer), a testing instrument from DIA-STRON Ltd., UK, was used (Müssig *et al*., 2005). In this method the individual tested elements were no longer clamped, but glued, in order to reduce the influence of clamping and were tested at a gauge length of 3.2 mm. The cross-sectional area of each element was measured by means of a laser beam. Then the sample was transferred automatically to the tensile testing system. Ninety elements were tested per sample. The free clamping length was 3.2 mm and the test speed was 2 mm/min.

5.7 Fiber length distribution

The Almeter AL100, an electronic apparatus for measuring length, was developed to test wool fibers. The device works with a specimen of fibers aligned in parallel using a preparatory machine called a Fibroliner. Detailed information has been published by Grignet (1981). The Fibroline instrument which is equipped with bast-fiber combs was used for sample preparation. The determination of fiber length of each type of fiber was carried out with fiber collectives. To prepare these fiber collectives 3 random samples of about 0.6 g each were taken from the fiber flock. All samples were prepared once with the Fibroliner instrument. The aligned fibers were then introduced into the Almeter and measured. The measurements were carried out per sample and for each sample the mean value of the measurements was formed. The statement of fiber length was related to cross-sectional length values. (Müssig *et al*., 2006).

5.8 Lignin content in fiber

Lignin content in hemp fiber were applied from TAPPI UM246 by Micro Kappa number method by Technical Association of the Pulp and Paper Industry (TAPPI, 1991). The useful method is design for testing semi-bleached pulps with lignin content as low as about 0.15 %, and for evaluation of materials from miniature pulping and bleaching experiment.

Hemp fibers of 0.5 cm length were diluted with 200 ml demiwater in a Blender and mixed for 1 or 2 minutes until the fibers had completely disintegrated. The suspension was transferred to a 800 ml beaker and a mixture of 25.00 ml 0.1 N potassium permanganate and 25.00 ml 4 N sulphuric acid was added at 25 °C. After 10 minutes of mixing with a magnetic stirrer at 25 °C, 5 ml 1.0 N potassium iodide was added. The liberated iodine was titrated with 0.1 N sodium thiosulfate with a starch indicator. The kappa number found was corrected to a 50% permanganate consumption. The samples were analyzed in 3 duplicate.

5.9 Cross-sectional view of fiber under SEM

Subsamples of hemp fiber were parallel into a group of fiber and put in the electrical tube. Dryer heat was applied to reduce size of tube as fit as the sample. Then fiber tube was cut at 5 mm length. Place on stub then sputter coated with gold particle and transferred to the specimen chamber of SEM. A series of 5 micrographs per sample was taken. Then measure fiber wall thickness and fiber diameter from 5 cell of each micrograph. Fiber diameter was measure from two dimension, one from the longest width (dimension 1) and another one from the 90 degree of the dimension 1 (dimension 2), then average the value from dimension 1 and 2 for fiber diameter.

6. Fiber yield

Fiber in this part was the same fiber source in topic 5. Fiber properties. Stem in each square meter plot were counted and measure stem height and diameter before subdivided into top, middle and bottom. Then bast and wood were separated by hand and dried under natural condition by avoid rain and fungi contamination. Each sample was weighed after dried and recorded. After bast fiber was separated by chemical retting and dried, fibers were weighed and recorded the fiber yield.

Places and Duration

1. Department of Botany, Faculty of Science, Kasetsart University, Chatuchak Bangkok, Thailand

2. Queen Sirikit Botanical Garden, The Botanical Garden Organization, Mae Rim, Chiang Mai province, Thailand

3. Huay Mae-Kieng highland agricultural station, Muang-Na District, Amphor Chiang Dao, Chiang Mai province, Thailand

4. Faserinstitut, Bremen, Germany

The research was conducted from January 2003 to September 2007

RESULT AND DISCUSSION

1. Planting location and climate

Planting location was established in Chiang Mai province, Northern Thailand. There are 3 seasons in the tropical climate. Summer was from March to June, rainy season was from July to October and coolly season was from November to February (Fig. 2). In summer, average temperature was 25 to 30 ºC and rainfall less than 50 mm per month. In June temperature was drop to 27 ºC and rainfall increased upto 100-320 mm per month, then rainfall was drop less than 100 mm and temperature decrease 2-5 ºC in October to February. Average relative humidity (RH) on May to October was approximately 80%. Then RH was decrease and become the lowest at 50% on April which is the warmest month of year.

In 2002, hemp was grown in Doi Baelae, Sob-Kong District, Amphor Omkoy, Chiang Mai province. This planting site was set for 2 sowing dates. The first sowing date (S1) was in July 28th and the second one was in October 14th (S2). Average temperature at S1 was 26.8 ºC, minimum and maximum temperatures were 21.6 and 32.9 ºC, respectively. Rainfall was 77 mm in July 2002. Average temperature at S2 was 25.7 ºC, minimum and maximum temperatures were 16.9 and 34.1 ºC, respectively. Rainfall was 145.2 mm in October 2002.

In 2003, at Huay Mae-Kieng high land Agricultural Station, Muang Na District, Amphor Chiang Dao, Chiang Mai province, 2 sowing date were grown. Average temperature in S1 was 28.1 ºC, minimum and maximum temperatures were 20.9 and 38.0 ºC, respectively. Rainfall in May 10th was 141.4 mm. In S2 the average temperature was 27.3 ºC, minimum and maximum temperatures were 22.7 and 34.8 ºC, respectively. Rainfall in July was 52.4 mm.

Planting location at QSBG in 2004 was located in Amphor Mae Rim, Chiang Mai province. Four sowing dates were established in this area. First sowing date (S1) was on July 27th , the second sowing date (S2) was on August 21st , the third sowing date (S3) was on September 13th and the forth sowing date (S4) was on October 15th 2004. Average temperature at S1 was 26.2 ºC, minimum and maximum temperatures were 21.9 and 34.2 ºC, respectively. Rainfall in July was 218.0 mm. At S2, the average, minimum and maximum temperatures were 26.6, 22.4 and 33.7 ºC, respectively. Rainfall in August was 115.7 mm. There was 26.7 ºC for average temperature on S3. Minimum and maximum temperatures were 22.8 and 30.7 ºC, respectively. Rainfall in September was 371.4 mm. At S4, average temperature was 26.3 ºC, minimum and maximum temperatures were 21.3 and 31.2 ºC, respectively. Rainfall in October was 38.8 mm.

Hemp was cultivated under natural precipitation. The detail of each site was below:

1.1 Doi Baelae, Sob-Kong Distric, Amphor Omkoy, Chiang Mai province
altitude : 1200 m above mean sea level, rainfall 1,612 mm (2002)
soil series : Doi Pui; soil texture : sandy loam; soil pH : 6.1; OM. 5.20 %
N 0.26 % P Available 26.39 K 701.25 Ca 47.46 Mg192.5

1.2 Queen Sirikit Botanic Garden, Amphor Mae Rim, Chiang Mai province
altitude: 800 m above mean sea level, rainfall 1,208 mm
soil texture: sandy clay loam; soil pH : 5.63; OM. 6.10 %;
N 0.30 % P Available 56.50 K 76 Sand 48.24 %; Silt 18 %; Clay 33.76 %

1.3 Huay Mae-Kieng high land Agricultural Station, Muang Na District, Amphor Chiang Dao, Chiang Mai province
altitude: 1000 m above mean sea level, rainfall 889 mm
soil series : Ta Yang; soil texture : sandy loam; soil pH : 6.7; OM 6.3 %

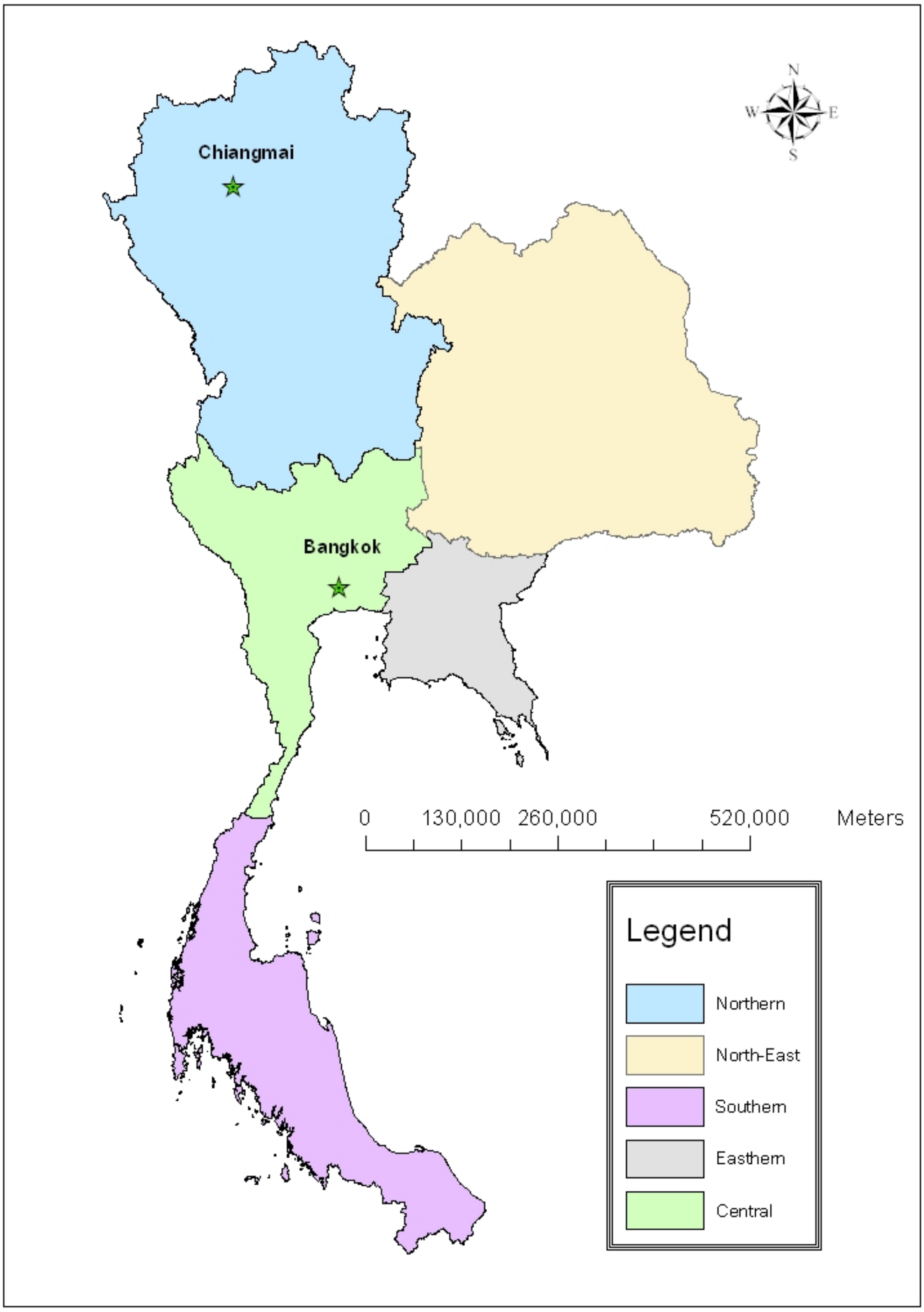


Figure 2 The location of Chiang Mai province in Thailand.

In 2002, average temperature was 21.5 °C in January then rise up to 29.3 °C in April. The maximum temperature was 39.8 °C and minimum was 19.8 °C in this month, while rainfall from January to April was less than 12 mm per month. In May, average temperature was decline to 27.8 °C and it was the beginning of rainy season. Average rainfall in May was 221.8 mm then dropped in July at 77 mm and rise to 254.7 mm in August and 309.7 mm in September. There was a second peak of rainfall, while the temperature stable among 27 to 28 °C from May to September. In October, rainfall drop to 145.2 mm and rise up to 332.3 mm in November as the third peak then dropped to 116.3 mm in November. Temperature declined from 25.7 °C in October to 22.8 °C in December, which was coolly season in Thailand (Fig.3).

In 2003, there was 21.2 °C in January then temperature rise up to 28.7 °C in April. The first peak of rainfall came on March at 53.5 mm and second peak in May at 141.4 mm. The third peak was the highest rain of the year 315.8 mm in September. Temperature was stable between 26.5 and 27.3 °C from June to October. Then temperature decline to 21.6 °C in December (Fig. 4).

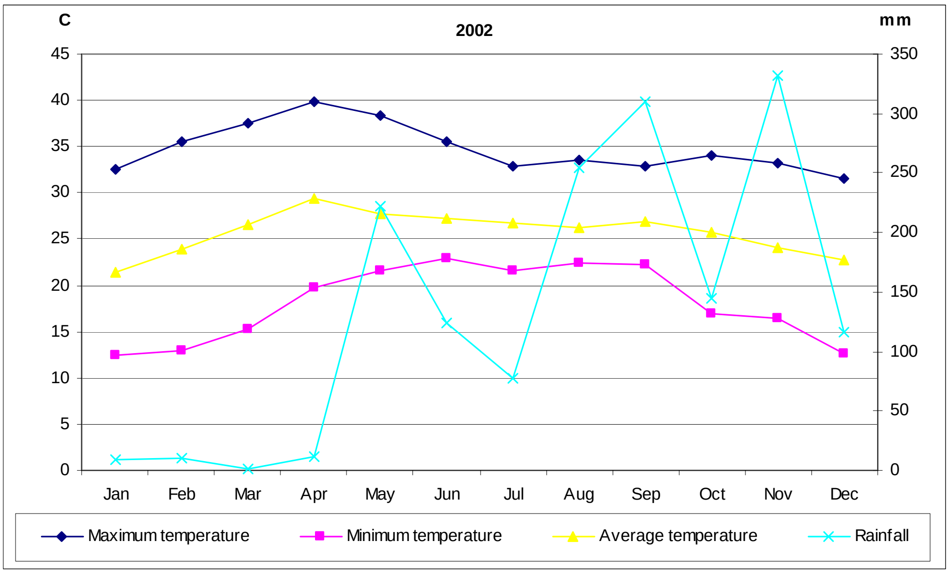


Figure 3 Climatic diagram of Chiang Mai province, Thailand. Data was adapted from meteorological record in 2002 by Thai Meteorological Department, Chiang Mai province.

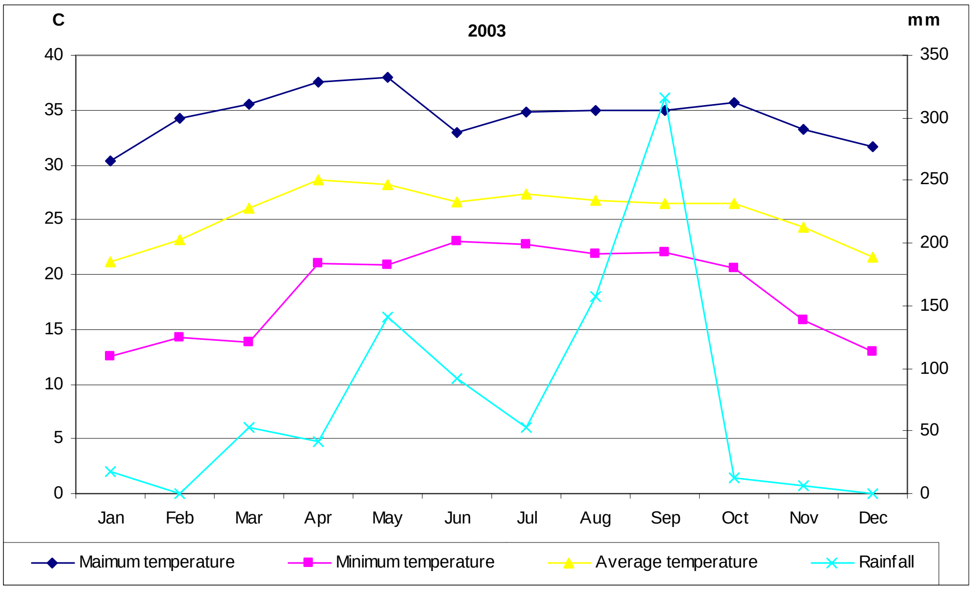


Figure 4 Climatic diagram of Chiang Mai province, Thailand. Data was adapted from meteorological record in 2003 by Thai Meteorological Department, Chiang Mai province.

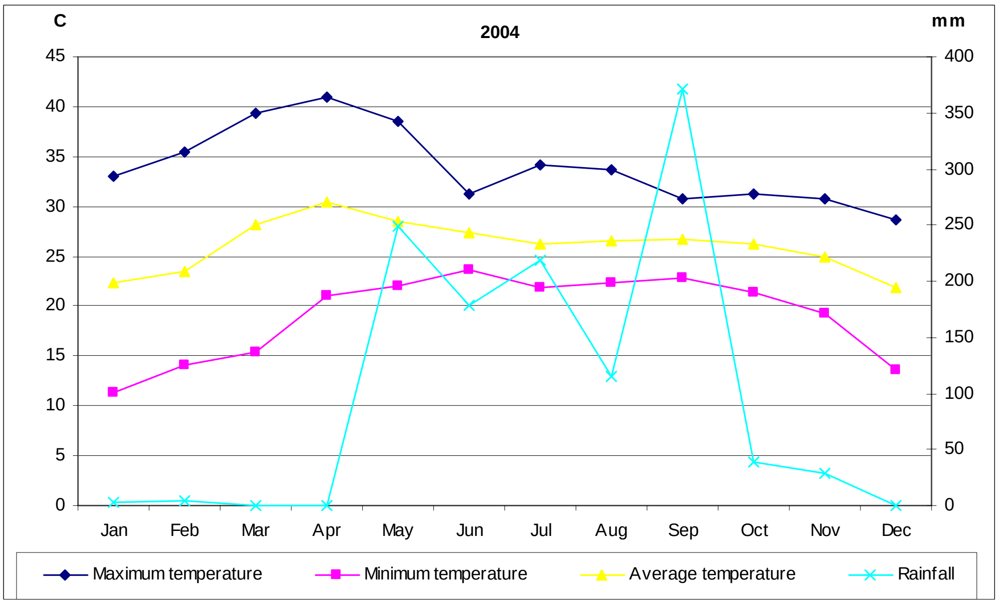


Figure 5 Climatic diagram of Chiang Mai province, Thailand. Data were adapted from meteorological record in 2004 by Thai Meteorological Department, Chiang Mai province.

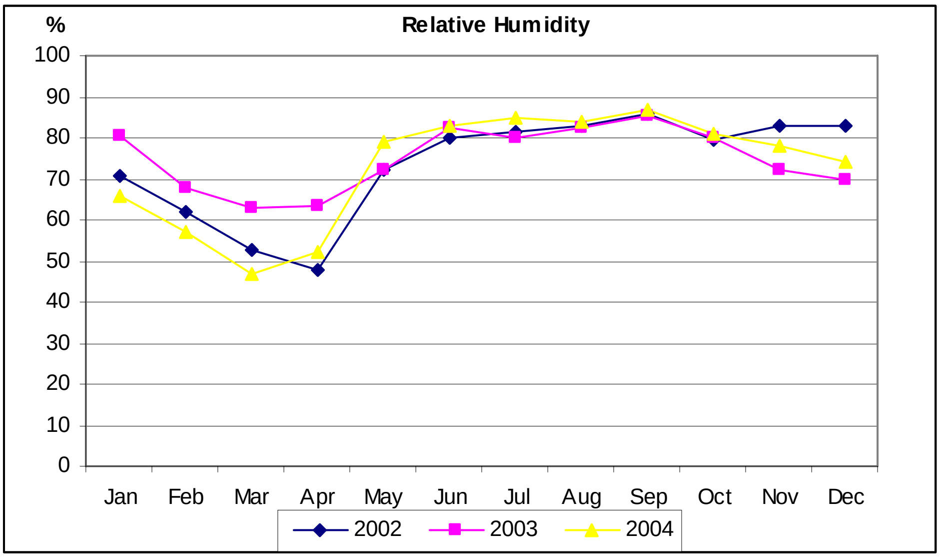


Figure 6 Relative humidity of Chiang Mai province in 2002 – 2004, recorded by Thai Meteorological Department, Chiang Mai province.

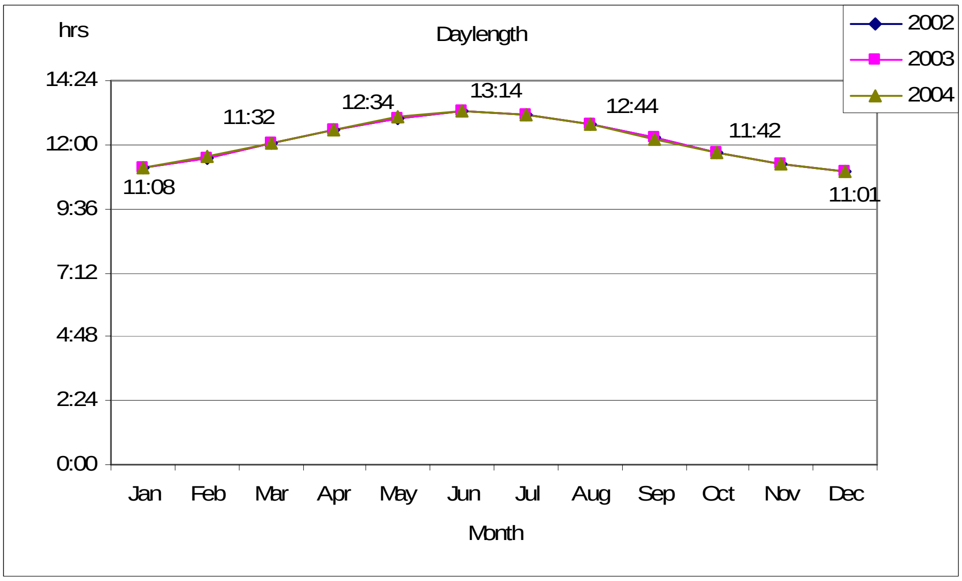


Figure 7 Daylength of Chiang Mai province from 2002 - 2004. Data from meteorology recorded by Thai Meteorological Department, Chiang Mai province.

In 2004, total rainfall was 1208 mm. From January to April, average rainfall less than 4.9 mm. There was 249.1 mm in May then decline in June. The rainfall rise to 218 mm in July and decline to 115.7 mm, then rise up to 371.4 mm in September. During May to October temperature was between 26.2 and 28.5 °C. In November, rainfall declined to 28.9 mm and no rainfall in December. During coolly season, temperature was decline to 21.8 °C in December (Fig. 5). The relative humidity from 3 years recorded was between 66 - 80 % in January, then decline to 48 - 63% in April. During June till October, relative humidity was approximately 80-87 % and decline in November (Fig. 6).

Photoperiod recorded from sunrise to sunset was stable for 3 years recorded. There was 11 hr 8 min in January then it increased to the longest photoperiod 13 hr 14 min in June. Then it declined to 11 hr in December which was a coolly season in Thailand (Fig. 7). The photoperiod in Thailand was stable because the country located near equator. Rainfall regime was the influence of monsoon with high humidity of tropical climate.

2. Preliminary study of hemp biology

2.1 Botanical and agronomical characteristics

Thai hemp was completely dioecious. Neither of monoecious nor hermaphrodite plants were found. At emergent there was dicotyledon with a simple leaf at first leaf pair. The second leaf pair was 3-lobed simple leaf, the third leaf pair was 5 lobes. Number of lobe on leaf increased from 3, 5, 7, 9 and 11 respectively. The most mature leaf had 7 or 9 lobes. Leaf margin was serrate. Leaf orientation with later development of leaves was opposite decussate at early stage of growth and changed to spiral upward. Stem was slightly 5 angular with green and robust. Male flowers were grouped in axillary or terminal panicle with few leaves. Tepals were 5 finely pubescent, stamen 5, anther loculicidal dehiscent. The anther dehiscent differed from the literature in the flora of Thailand (Phengklai, 1981) that reported the dehescing by an apical pore. Female flowers were solitary at axil and terminally arrange in spike.

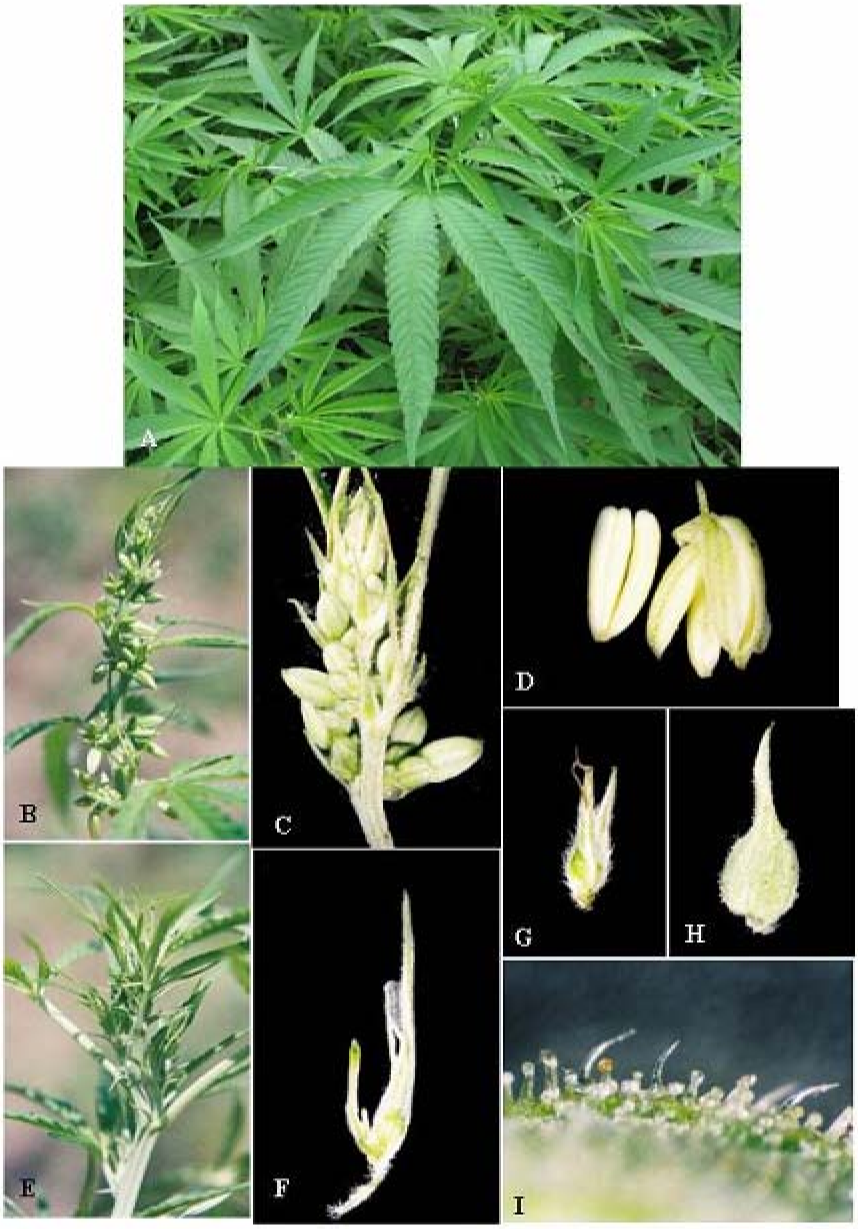


Figure 8 Morphology of hemp leaf, male and female flower

A: hemp leaves; B,C: male inflorescence; D: male floret;

E: female inflorescence; F: female floret; G: pollinated floret;

H: seed development; I: glandular trichome on female bract

Each flower was enveloped by a membranous spathe-like, dark green bract with glandular trichome, perianth absent, ovary 1-locule, style short divided into 2 long stigmatic arms with 1 ovule. Style was white or red (Fig.8). Fruit was achene, smooth, shining, brownish, ovoid shape. Thai hemp was same botanical characteristics as Hatton (1999) and Promratrak (2002) had reported. Although hemp is dioecious, some varieties were monoecious such as Futura 75 which originate in France (Amaducci *et al*., 2005). For dioecious, it is not uncommon for an individual plant to bear both staminate and pistillate flowers. The occurrence of monoecious plants is more common when the daily exposure to light is short and under experimental condition (Schaffner 1926; Hayward 1984).

The phyllotaxis of hemp was both opposite and alternate, and ordinarily the lower leaves were arranged in opposite pairs while the upper ones were alternate (Schaffner, 1926; Hayward, 1984). As the results of our studies, phyllotaxis of hemp was opposite decussate at early state of growth and changed to spiral. Thus, the abbreviation in this report termed ‘opposite decussate’ instead of ‘opposite’ and termed ‘spiral’ instead of ‘alternate’, which differed from previous literature. The inflorescences were subtended by an amount of reducing three lobes leaflets, which were small awl-shaped laterals.

There were node and internode on the stem. Stem at maturity was obtusely hexagonal, more or less grooved or furrowed and have a hollow stem. Stem was green or brown, a bark can peeled from woody part. In general, bast was called for peeled bark.

Hemp was reported as short day plant with the critical photoperiod of 14 hrs (Lisson, 2000c). Thailand, the tropical country had a photoperiod between 11-13 hrs (Fig. 7). Then the cultivation in 2002 were investigated in 2 sowing date for the preliminary study of Thai hemp to the photoperiod and natural climate of Thailand. The first sowing date (S1) was investigated on July 28th and the second sowing date (S2) was on October 14th in 2002. S1 was investigated in rainy season while S2 investigated in the beginning of coolly season. When S1 was 139 days and S2 was 62 days on December 15^{th}, hemp on both S1 and S2 were in stage of seedset. Monoecious plant was not found in population. Stem height of S1 was 130.5 and 104 cm in male and female plant, respectively. While diameter of S1 plant was 9 and 8 mm in male and female plant, respectively. Height of S2 plant was 56 and 30 mm in male and female plant, respectively. Both male and female performed the equal diameter at 5 mm. The result showed the male plant had a higher stem than female (Table 4).

S1 was a time of rainy season and S2 was the end of rainy season and beginning of coolly season. S1 and S2 begin at different time of planting but perform the same time of seedset, thus the flowering of hemp was induced by day length on November or previous one. The day length of Chiang Mai province was 11-13 hrs (Fig. 7). This indicated that Thai hemp had a critical photoperiod different from the temperate hemp.

The duration of daylength is defined as the interval between sunrise and sunset. Under natural conditions, the duration of daylight varies over the earth's surface, and is dependent on season and latitude (Boyle, 2007). Civil twilight is defined as the interval between sunrise (or sunset) and the time when the sun is 6° below the horizon. The light intensity at sunrise and sunset is often greater than 20 foot candles. Light at very low intensities, *i.e*, civil twilight, is sufficient to induce photoperiodic responses in plants. For example, light intensity of less than 2 ft-c is sufficient to inhibit normal flower bud initiation in poinsettia, a short-day plant. Thus, for photoperiodic responses, photoperiods should estimated by adding the periods of civil twilight to the duration of daylight (List, 1951). Unfortunately the data of daylength in Chiang Mai province was calculated from the meteorology recorded which performed from sunrise and sunset.

2.2 Hemp anatomical structure

2.2.1 Root

Hemp had tap root system. Primary growth of root had 2 groups of vascular bundle, called diarch (Fig. 9B). Endodermis had a thicker wall, arrange surrounded the vascular cylinder or stele (Fig. 9D). Pericycle was a parenchyma cell next into endodermis, at early stage of vascular system clearly presenting of phloem, protoxylem and metaxylem. The outer most was epidermis follow by hypodermis. Cortex composed of parenchyma with thin wall cell.

The secondary growth of root showed the phellogen (periderm) that developed from pericycle (Fig. 9E) at the outer most. Bast fiber and lignified wall of vessel supported the root in the secondary growth. Outside of the vascular cambium was secondary phloem and inside was secondary xylem (Fig. 9F). Cross sectional view was as ordinary dicotyledons root as reported by Esau (1977) and Hayward (1984).

2.2.2 Leaf

Hemp leaf was green, viscose, simple or lobe. Main midrib was large and vein with vascular bundle. There was many layers of parenchyma and multiple epidermis at midrib. Leaf blade had one layer of epidermal cell on adaxial leaf surfaces, non-glandular trichome was located at both side of leaf blade. Non-glandular trichome on adaxial leaf surface was an individual large basal cell with acute and short apex. This trichome is called crystolith hairs (Fig. 10).

There was a non-glandular trichome that called hair on the abaxial leaf surface. Hair was acute, long and with non basal cell. Palisade cell lies under epidermis and connected to spongy cell. Lower epidermis was one layer where stomata had occurred.

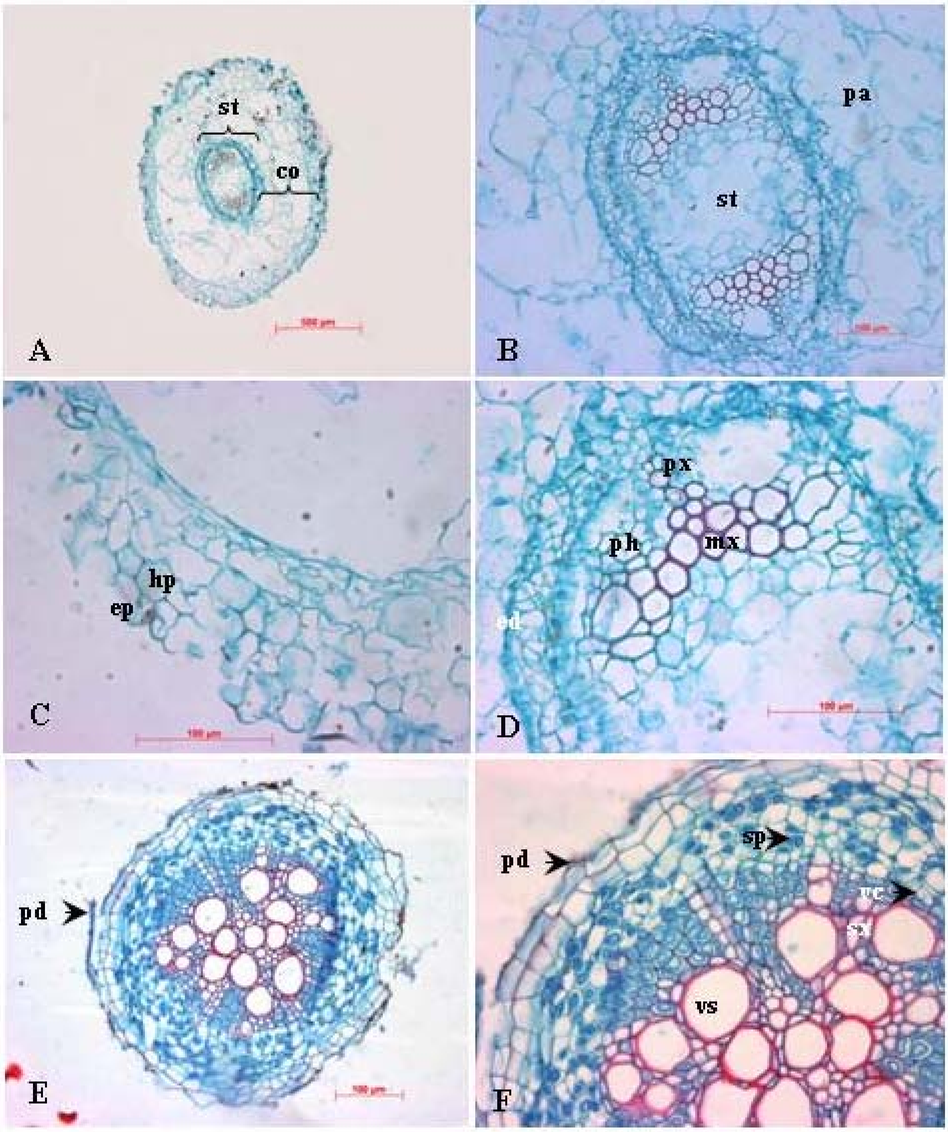


Figure 9 Anatomical structure of hemp root cross sectional view
A,B,C,D : primary growth; E,F: secondary growth
A: cross sectional view of hemp root at primary growth stage
B: stele of hemp root at primary growth; C: multiple epidermis
D: endodermis and vascular bundle; E: cross sectional view of hemp root at secondary growth; F: internal structure of secondary growth of root
co: cortex; ed: endodermis; ep: epidermis; hp: hypodermis;
mx: metaxylem; pa: parenchyma; pd: periderm; ph: phloem;
px: protoxylem; sp: secondary phloem; st: stele; sx: secondary xylem
vc: vascular cambium; vs: vessel

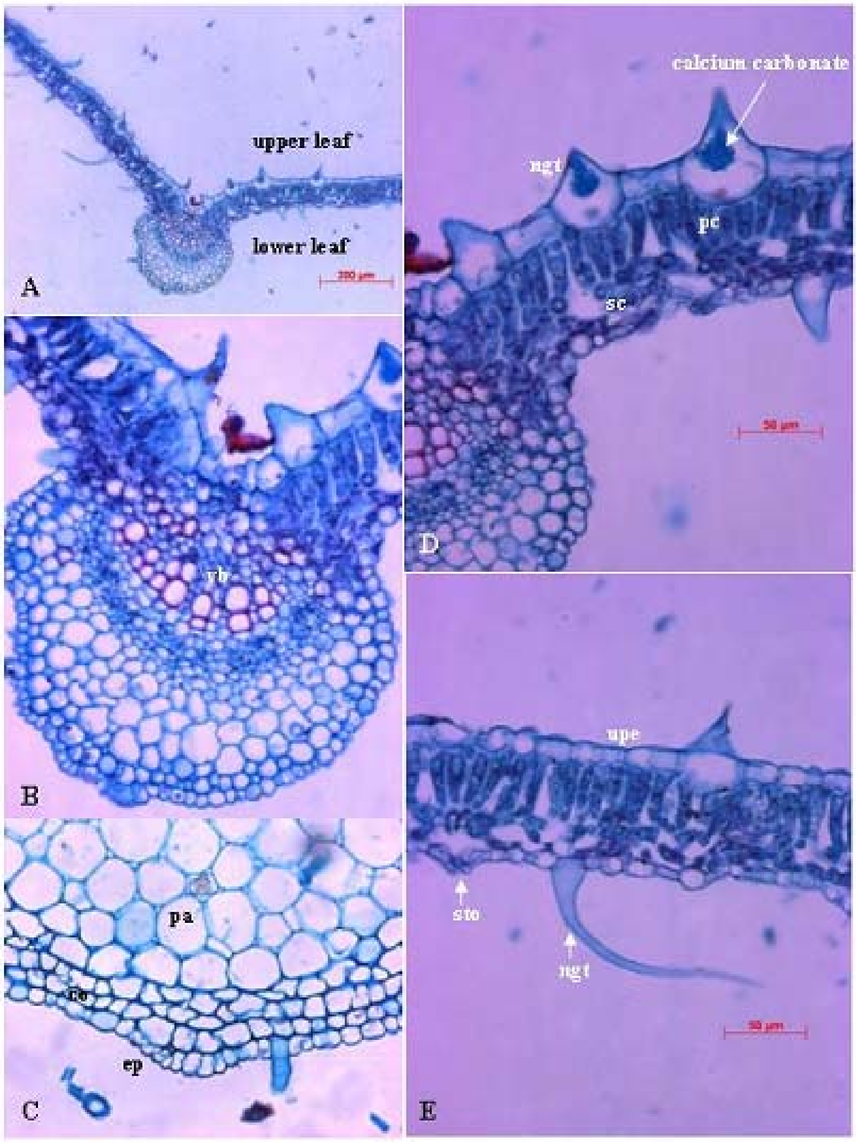


Figure 10 Anatomical structure of hemp leaf
A. B. C.: midrib; D. E.: leaf blade
co:collenchyma; epidermis; gt: glandular trichome;
ngt: non-glandular trichome; me: multiple; pa: parenchyma;
pc: palisade cell; sc: spongy cell; sto: stomata; upe: upper epidermis;
vb: vascular bundle

Hemp had many types of trichome on aerial part. To demonstrate trichome in cannabis, the view from SEM was showed in Fig. 11. Glandular trichome in cannabis termed bulbous, capitate-sessile and capitate-stalked (Hammond and Mahlberg, 1973). Three morphologically distinct types of glandular trichome differed in size and the appearance of stalk. Bulbous and capitate-sessile glands occured on all parts of vegetative and flowering shoots except for hypocotyls and cotyledons. In contrast, capitate-stalked glands are restricted to flowering regions. For these glands were believed to be the primary site of synthesis of the important narcotic agent, tetrahydrocannabinol (THC) (Hammond and Mahlberg, 1973; Dickison, 2000).

Non-glandular trichomes that covered the plants were of two major types. The predominantly crytolith-containing hairs are found on the adaxial surface of the leaves. The differences size and the existence of warty protuberances were able to distinguish the two kinds of cystolith hairs. About 15-20 epidermal cells form a circle at the base of the cystolith hairs. Long cystolith hair was ring surrounding basal cell (Fig. 12C) while short cystolith hair was a smaller surrounding basal cell (Fig 11A). It contains a secondary substance (Fig. 10D), which had reported that it was calcium carbonate ($CaCO_3$), rule as protecting substance that avoid plant from animal and insect (Dickison, 2000). Non-glandular trichome on abaxial side was a long hair cell. Both glandular and non-glandular trichomes cover the shoot system of cannabis from the early seedling stage to maturity (Dayanandan and Kaufman, 1976).

2.2.3 Stem

At early stage of growth, the young stem developed an eustele (Esau, 1977), that was character of phloem connect outside xylem which arranged in group at early state of growth and separated by interfascicular region. Pith located at central of stem, the central of node is parenchyma, central of internode is hollow of air space (Fig. 13). The outermost of stem was epidermis, hypodermis and cortex, respectively.

When stem grow up, the secondary growth of stem perform when secondary xylem increase and each group of bundle fused around stem. Transverse cross section of stem showed the shape of round with corners (Fig. 13). The overview of stem cross section could divided as woody core and bast, which separated by the difference color of cell wall stained. These two parts could divided by vascular cambium. Epidermis was the outer most where glandular trichome and non-glandular trichome was located (Fig.15B). Primary phloem or primary bast fiber was irregular cell connect to each other around the stem in secondary growth. These called pericyclic fiber. Primary bast fiber cell was blue of fast green show high content of cellulosic cell wall (Ruzin, 1999). Secondary xylem composted of xylem vessel and xylem fiber of red wall of safranin means the rich of lignified and suberized cell wall. Pith was the innermost, composted of a thin wall of large parenchyma cell. At the center of stem was hollow at internode section.

At top part of stem, pith was the largest area and continues to the central stem cross section (Fig. 18A). The middle part of stem was represented as the whole stem anatomical feature (Fig. 16). Primary bast fiber of a side and corner of stem were difference (Fig. 16F, 16G). Primary bast fiber at stem corner showed more amount of secondary bast fiber which smaller than primary bast fiber (Fig. 16G). Primary bast fiber at each side of stem showed the larger cell (Fig. 16F) than primary bast fiber at stem corner (Fig. 16G).

Stem cross section from the bottom part (Fig. 17) showed the different pattern of one to another side of stem. Ordinary stem cross section was shown in Fig. 17B. While another side of stem from the same specimen was shown in Fig. 17C. In this figure, xylem was separated from bast with the zone of two-wall layer, where primary and secondary wall was distinguished (Fig. 17H). The figure showed high lignin and suberin on primary wall as red wall. Conversely, the secondary wall was high in cellulose, hemicellulose, and pectin but lower lignin by dominate of blue wall. The mature plant produced periderm as the outermost cell instead of epidermis (Fig. 17D).

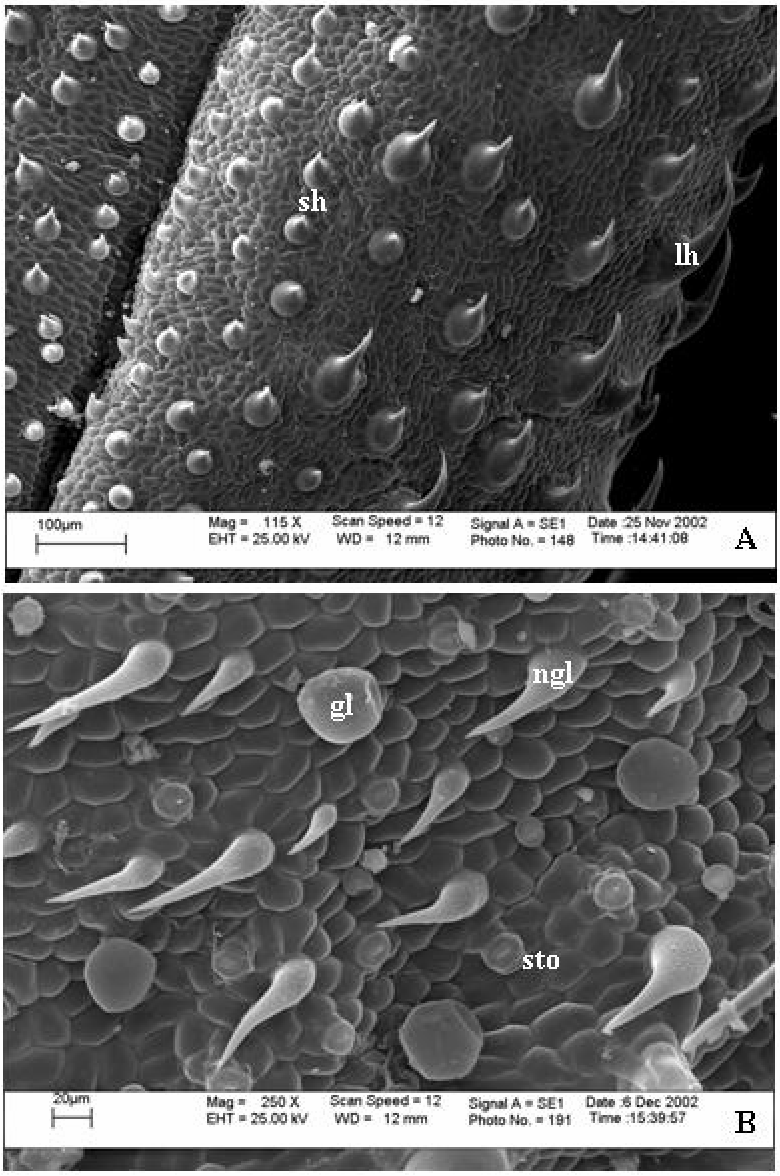


Figure 11 Scanning electron micrograph of external surface of hemp bract

A. Adaxial leaf surface showed the two major of non-glandular trichome,

B. Abaxial leaf surface showed stomata, non-glandular and glandular trichome

gl: glandular trichome; lh: long hair; ngl: non-glandular trichome; sh: short hair; sto: stomata

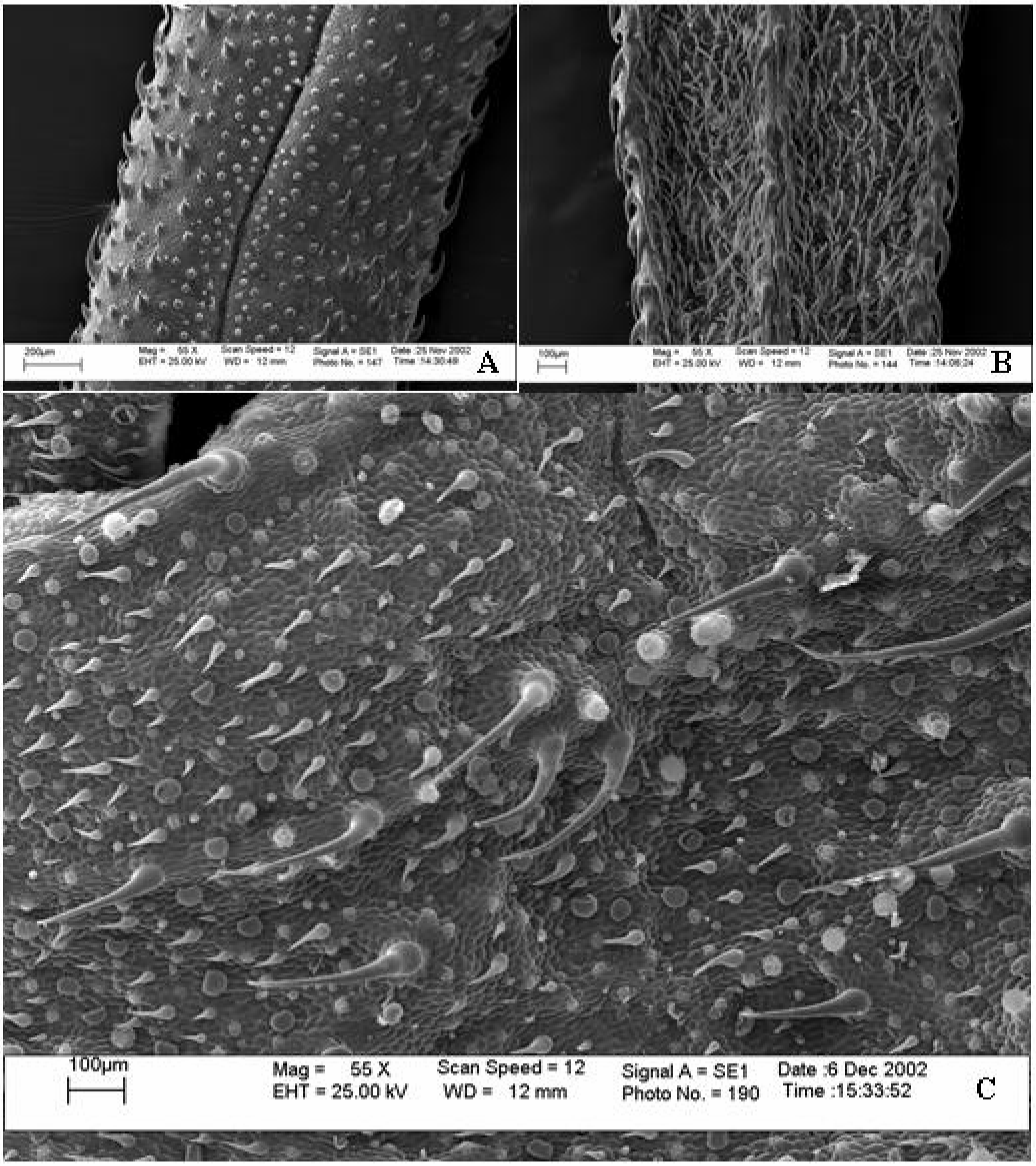


Figure 12 Scanning electron micrograph of external surface of hemp leaf and bract

A. Adaxial leaf surface of female hemp covered with non-glandular trichome

B. Abaxial leaf surface from the same specimen with A. showed that leaf area was cover with non-glandular trichome

C. Abaxial bract from female floret showed glandular trichome and non-glandular trichome

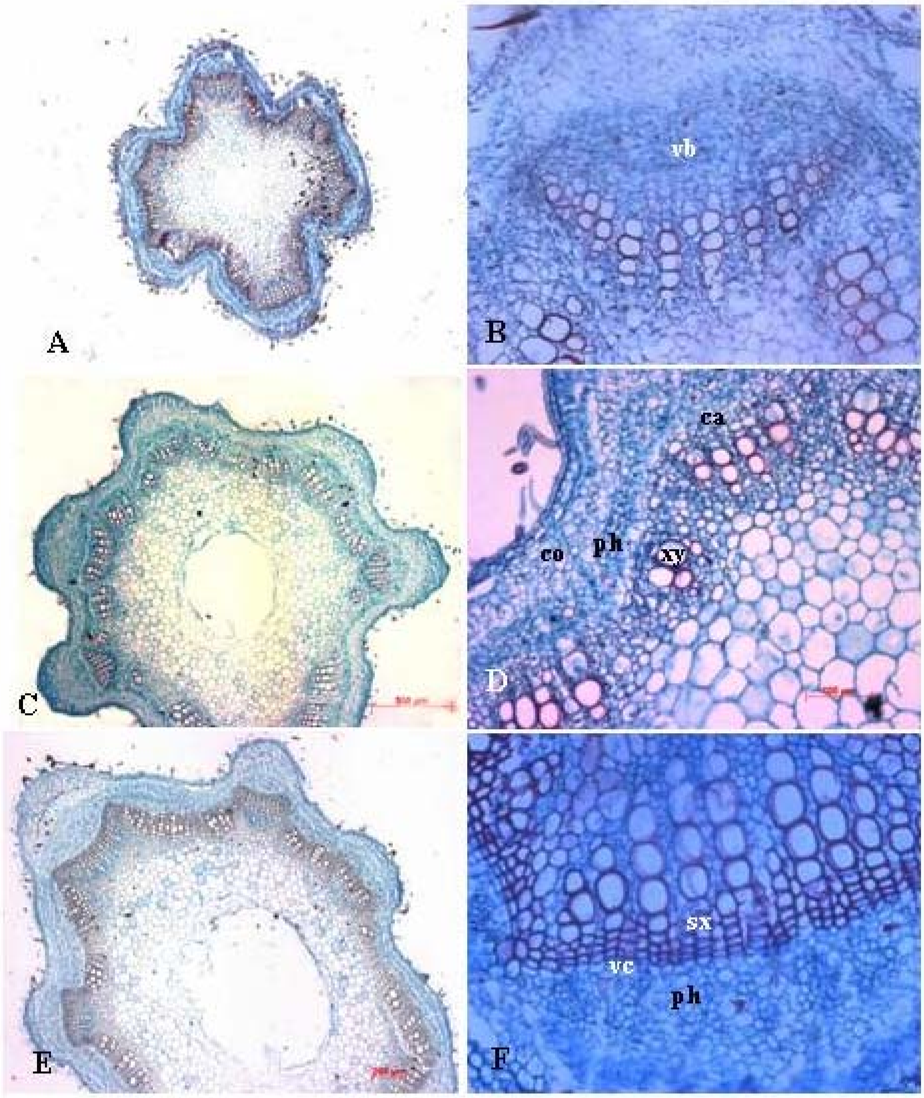


Figure 13 Primary growth of hemp stem
A.C.E. cross sectional view of hemp stem
B. D. vascular bundle at primary growth; F. vascular bundle at early stage of secondary growth
ca: cambium; co: cortex; vb: vascular bundle; ph: phloem; sx: secondary xylem; vc: vascular cambium; xy: xylem

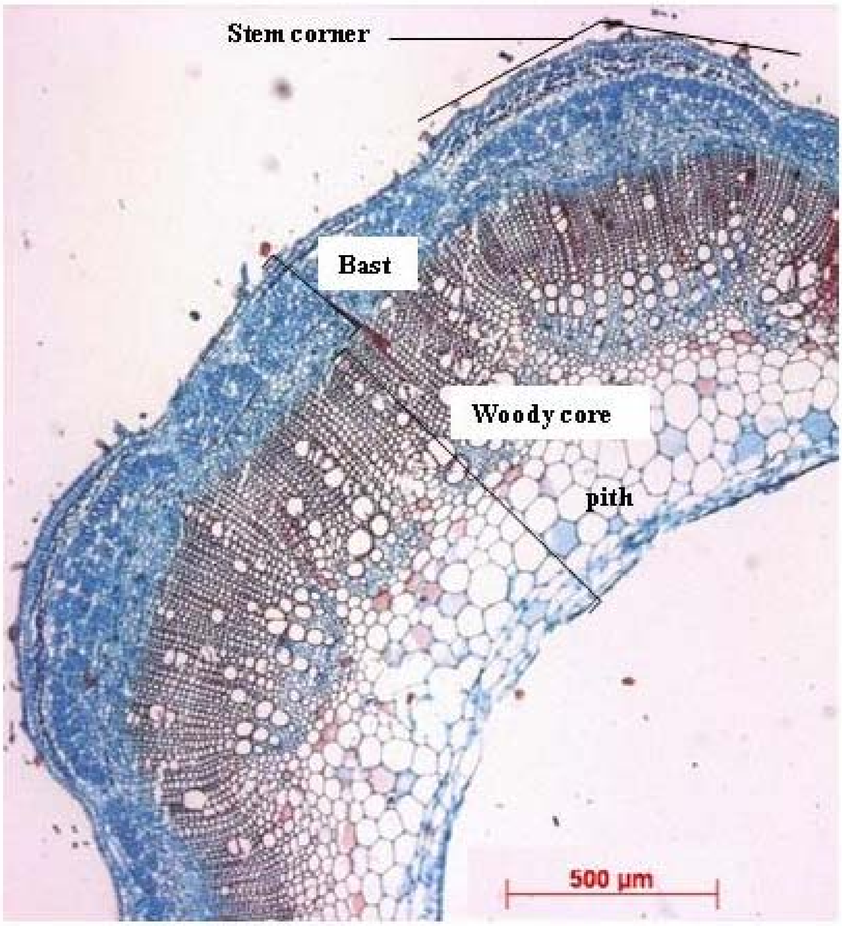


Figure 14 Cross sectional view of mature hemp stem from Doi Baelae, Chiang Mai in 2002

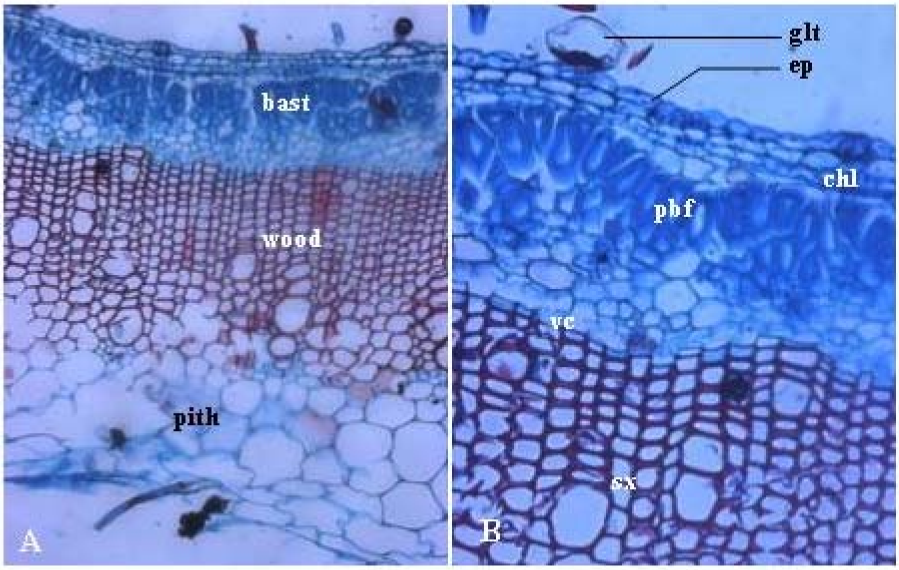


Figure 15 Cross sectional view of male hemp stem from Doi Baelae, Chiang Mai in 2002
A. bast and wood in stem cross sectional view; B. bulbous gland, one type of glandular trichome in hemp
chl: chlorenchyma; ep: epidermis; glt: glandular trichome; hp: hypodermis; pbf: primary bast fiber; sx: secondary xylem; vc: vascular cambium

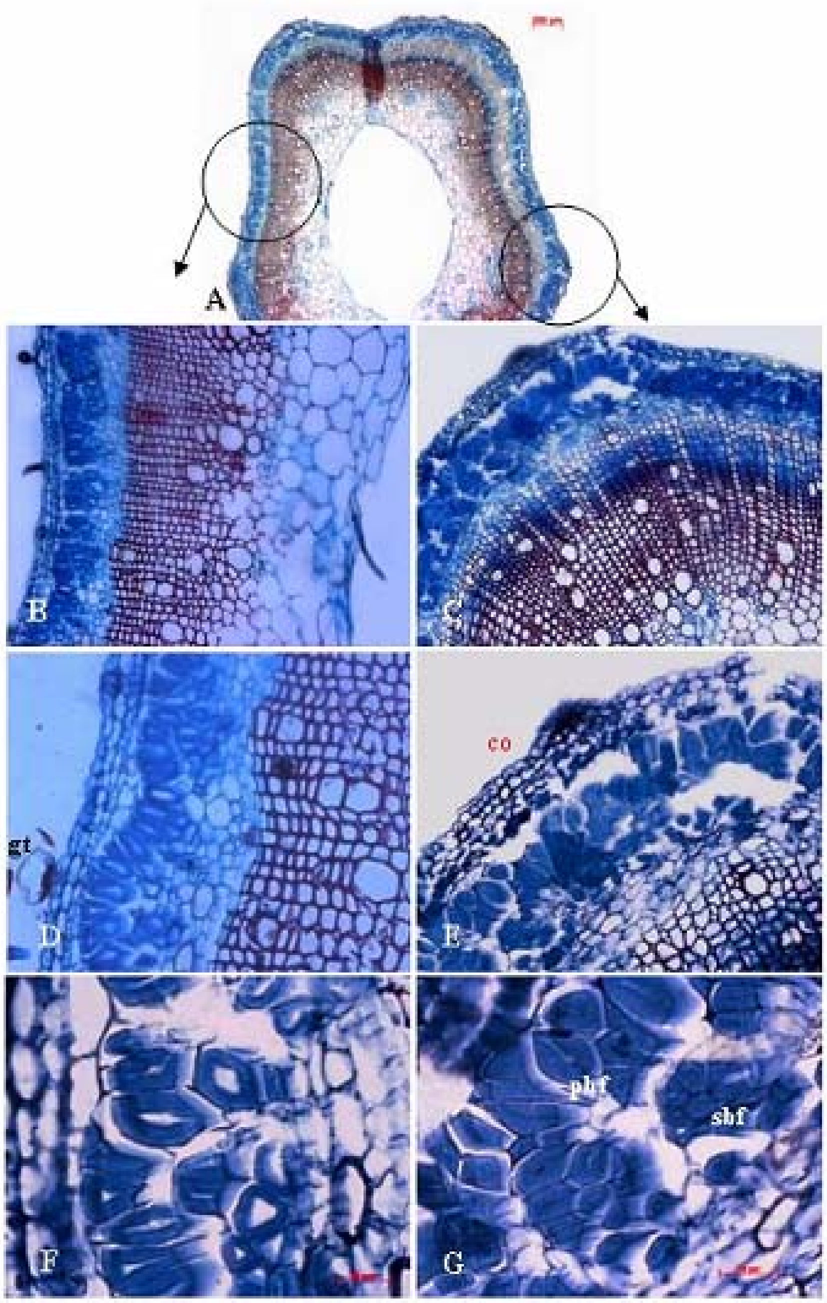


Figure 16 Cross sectional view of middle part of mature hemp stem from Doi Baelae, Chiang Mai in 2002
A. The overview of whole specimen (5x)
B, D, F. Figures from one side of stem B,C 20x ; D,E 40x ; F,G 100x
C,E,G. Figures from stem corner
gt: grandular trichome; pbf: primary bast fiber; sbf: secondary bast fiber

The two-wall layer is however a common feature of plant cell, where a primary and a secondary wall can be distinguished. In supporting tissue (*i.e.* fibers) the secondary wall become extremely thick and it is modified to a various degree by lignin deposition. The thickening layers are deposited one after the other. Lignin deposition starts well before fiber wall complete thickening. It is first occurs in middle lamella and in outer (primary) wall layer and proceeds inwards. Mature xylem and phloem secondary fiber, both produced by cambium during secondary growth, are generally quickly and heavily lignified. In bast fiber (as hemp textile fiber) lignin deposition mainly occurs in the outermost cell wall layer; a lighter lignification than continues in a centripetal way involving the secondary wall layers. In Fig. 17G-H both recently formed xylem fibers and bast fiber show detached and partly infolded secondary wall. This feature is unusual, but explainable.

First it occurs in immature fiber, where lignification is poor and uneven; handling specimens before or during the fixation, inclusion and staining procedures could determine such distortions. Due to cellulose hydrolysis as observed similar features in hemp secondary wall following iodine-sulphuric acid staining, which reported by Bonatti *et al* (2004).

Second, this appearance of two-wall layer is uneven around the stem, this may explained by the phenomenon in supporting tissue, when the secondary wall becomes extremely thick and it is modified to a various degree by lignin deposition. This can be the environmental impact such as wind and stretch that put the weight to one side of plant as occur in reaction wood (Dickison, 2000).

Cell maturation and fiber maturity varied within individual plants from stem bottom upwards and within individual bundles (Fig. 18). The secondary bast fiber presented both bottom and middle of stem, but less at the top of stem (Fig. 18D, 18F). The two-wall layer was found both bottom and middle section (Fig. 18C, 18E).

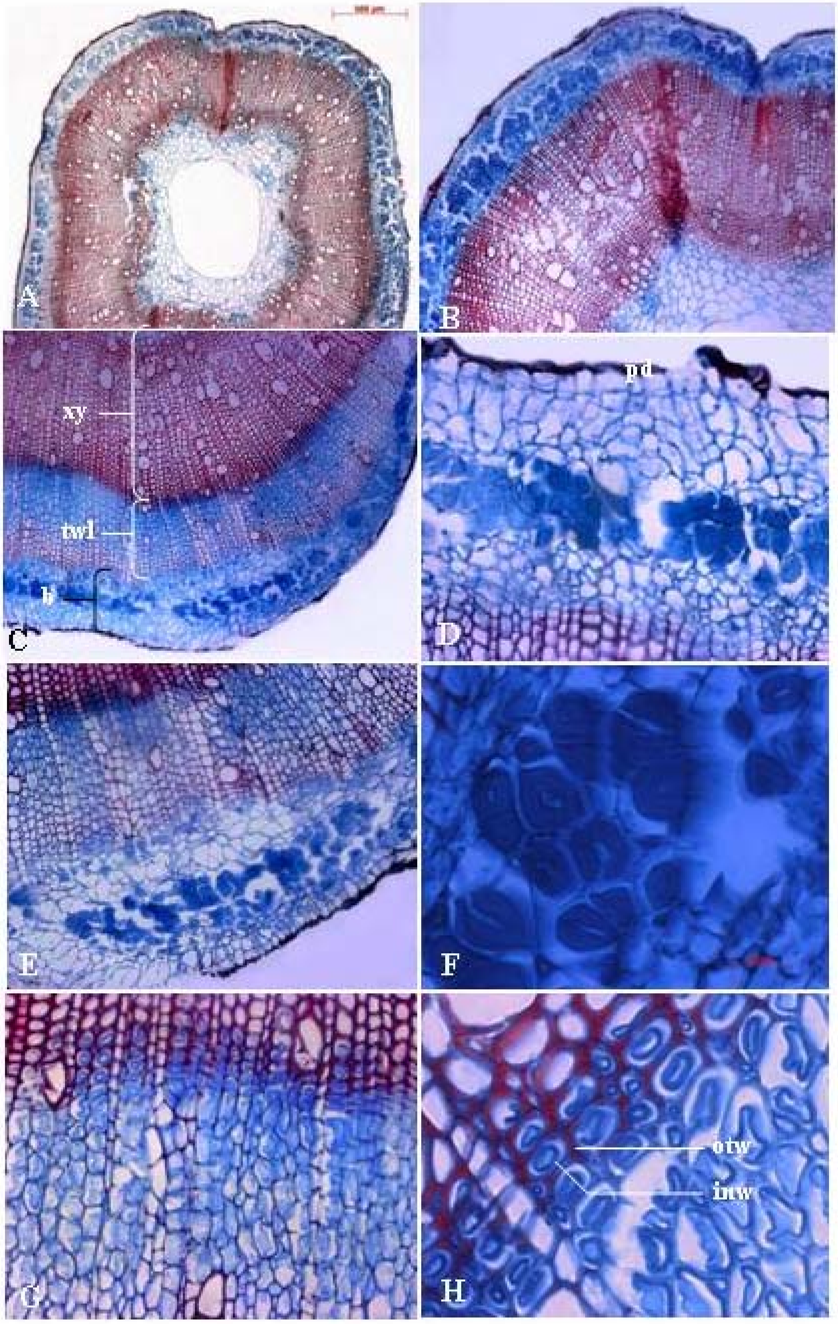


Figure 17 Cross sectional view of botom part of mature hemp stem from Doi Baelae, Chiang Mai in 2002
A. An overview of stem cross section B. Normal stem cross section
C. Stem cross section show the two-wall layer zone
D.Normal bast fiber; E. F. Bast fiber cell (100x) G. Two-wall layer zone
H. Two-wall layer show lignified of outer wall and cellulose at inner wall(100x)
xy: xylem; twl: two-wall layer; pd: periderm; b: bast; inw: inner wall; otw: outer wall

Thai hemp perform most primary bast fiber in bast while other hemp variety can produce both primary and secondary bast fiber (Fig. 19). The occurrence of secondary bast fiber can be developed during growth and development of stem. The priority of occurring of secondary bast fiber was highly impact by genetic control follow by environment factors (Amaducci *et al*., 2005). The secondary bast fiber of Thai hemp may not arrange beneath the primary bast fiber clearly as occur in variety Futura (Fig. 19C), but can occur in primary bast fiber layer (Fig. 16E, 16G) or in phloem area. For long fiber uses such textiles and composites, the stem value depends primarily on the proportion of bast fibers. It is commonly known that a high bark yield and bast fiber content as well as a low secondary bast fiber content are advantageous for the production of textile (Mediavilla *et al*., 2001).

2.3 Fiber morphology

After maceration, fiber cell were measured. The result of primary bast fiber was 25 µm width, secondary bast fiber was 16 µm width with 3.4 mm length. Average size of core fiber was 20.23 µm width and 0.62 mm length. Core fiber from bottom had a longer length than fiber from top. There was significant difference of core fiber length from each part of male stem but non significant difference in each part of female (Table 5). Highly different of fiber length among male (0.6783 mm) and female (0.5587 mm) were found. Fiber width was not difference in each part but hightly different between male (22.74 µm) and female (20.23 µm).

Morphology of bast fiber showed surface marking on fiber (Fig. 21B). This exhibit were called dislocation and cross-marking which are prominent in bast fiber. According to the shape of fiber ends which defined by Catling and Grayson (1982), bast fiber was blunt and core fiber was pointed ends (see Appendix Figure 1). This character was specific to fiber in each plant species (Ilvessalo-Pläffli, 1995).

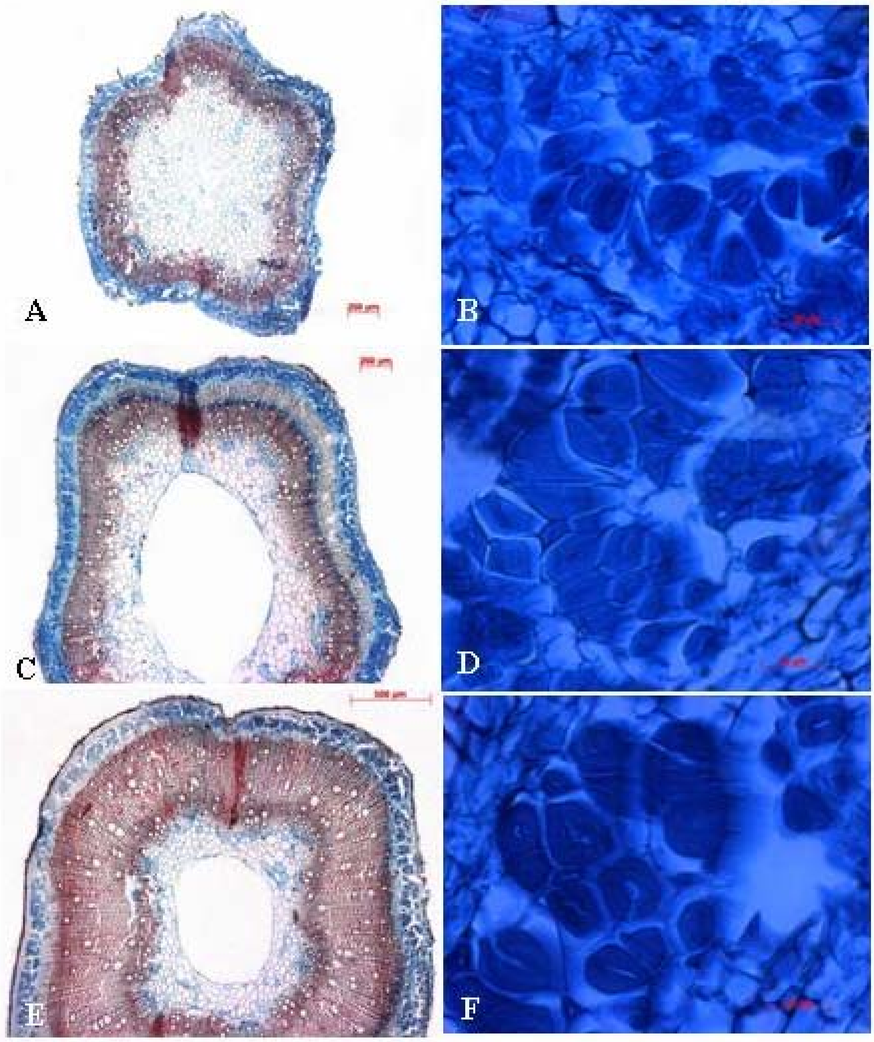


Figure 18 Cross sectional view of mature hemp stem from top, middle, and bottom stem, Chiang Mai in 2002
A. Cross section of top part B. Primary phloem in top part (100x)
C. Cross section of middle part D. Primary phloem in middle part (100x)
E. Cross section of bottom part F. Primary phloem in bottom part (100x)

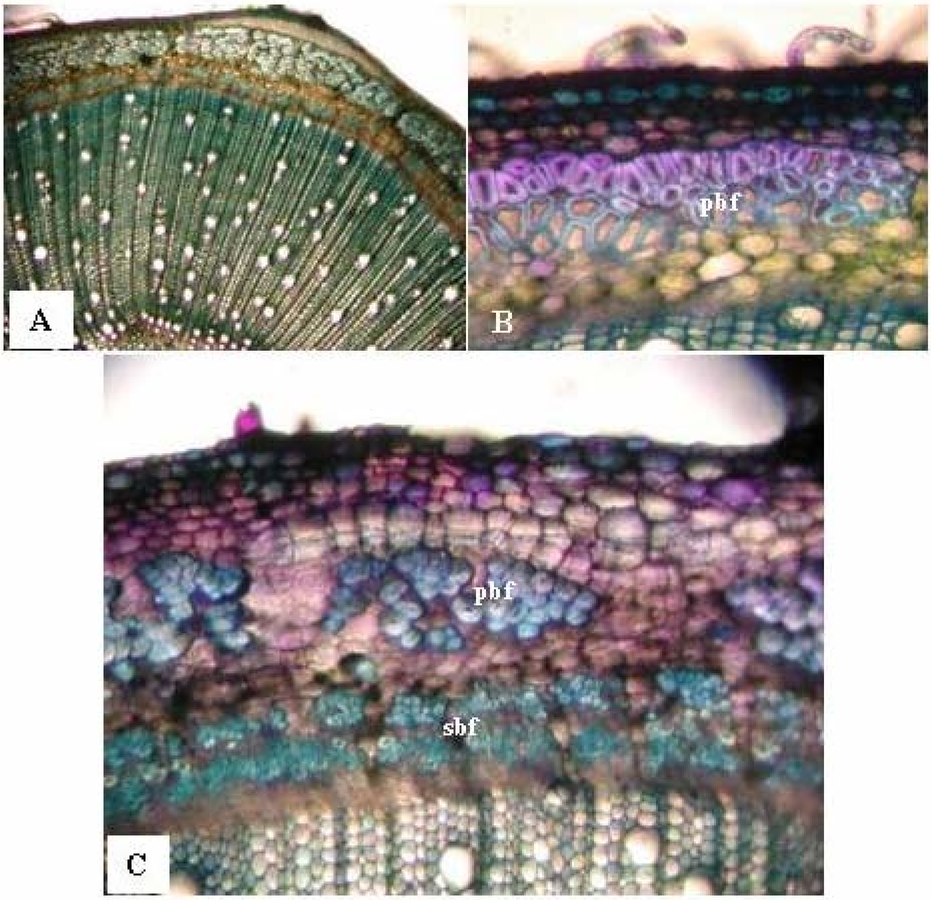


Figure 19 Cross sectional view of hemp stem variety Futura
(printed with permission from Amaducci *et al*., 2005)
A. Cross sectional view B. Less secondary bast fiber
C. Section of hemp show primary bast fiber and secondary bast fiber
pbf: primary bast fiber; sbf: secondary bast fiber

The result of macerate application performed the difference reaction among fiber and technique. Jeffrey's method was applied to bast and woody core. The maceration from this technique performed successfully separated to core fiber but damage bast fiber (Fig. 20A and 20C). Most bast fibers was damaged into short segment but few of them can stand still to the solution. These fibers were less width than damaged fiber. One hypothesize of this fiber may have higher lignin content in fiber wall. These fibers should be the secondary bast fiber.

Generally the natural fibers of vegetable origin are weak in acids and strong in alkalis (Nakamura, 2000). Jeffrey (1917) was a treatment using a mixture of equal portions of freshly combined 10 % nitric acid and chromic acid. Thus, acid solution in this method and high temperature treatment damaged bast fiber which low lignin content. But core fiber in woody core which contain high lignin on wall can resist to the solution. Then successful separated into individual cell can occurred only on core fiber.

To find the suitable separated technique, Franklin's method was applied to bast. Acetic acid and hydrogen peroxide are used in Franklin's method (1945). This maceration processes as well as bleaching with less acidic solution in treatment, bast fiber from this method remain as a complete singular cell (Fig. 21).

For maceration, the experimented plant is treated with chemicals which dissolve the middle lamella and allow the cells/fibers to become separated from one another. It should be emphasized that in some types of plants, the mild maceration process was not completely dissociate to a single fiber unit, resulting in an aggregate of fibers. Conversely, the strong maceration process could damaged the fiber structure. Moreover, time and temperature treated should varies to each fiber for successful separation a single cell.

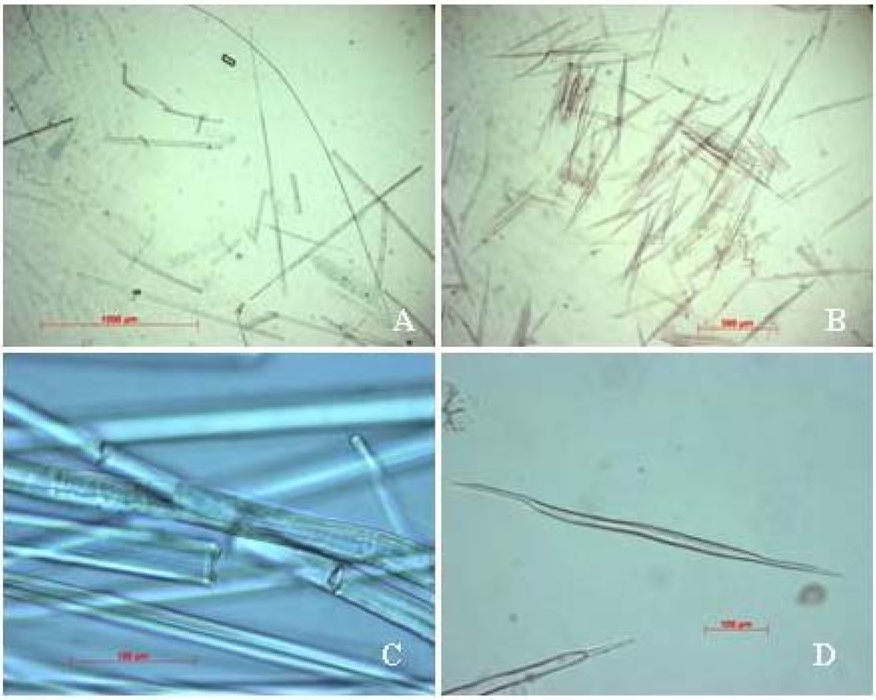


Figure 20 Bast and core fiber from Jeffrey's method
A Bast fiber B. Aggregated core fiber
C. Damaged bast fiber D. Complete core fiber with pointed ends

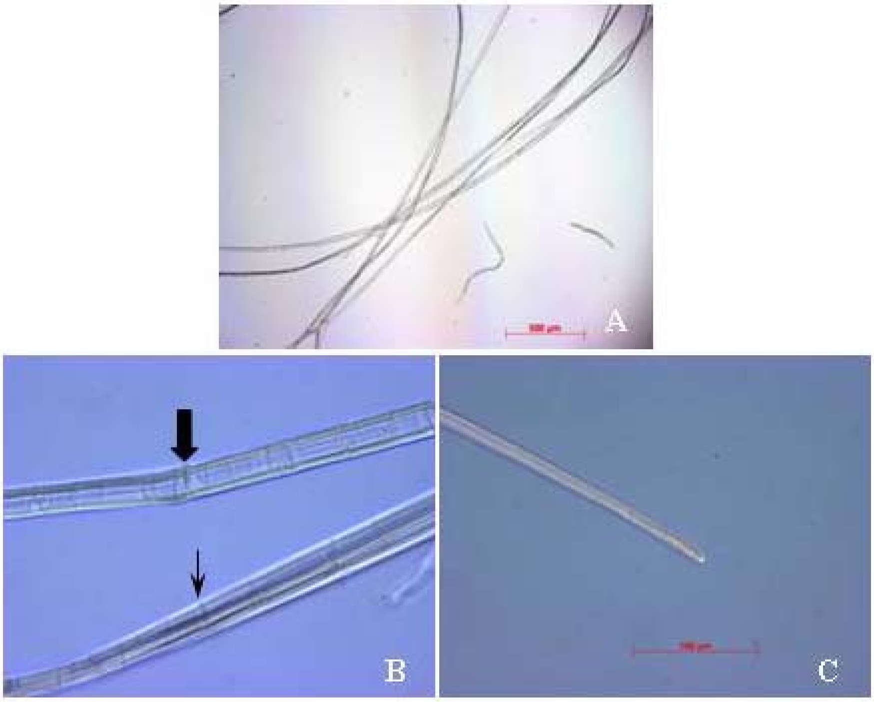


Figure 21 Macerated bast fiber from Franklin's method
A. Single bast fiber (5x)
B. Cross making (line arrow) and allocation (dark arrow)
C. Bast fiber with blunt ends

Table 4 Plant height and diameter at day of seed set grown at Doi Baelae, Chiang Mai province in 2002.

Sowing date	Day to seed set (days)	Height (cm)		D_{10} (mm)	
		Male	Female	Male	Female
S1	139	130.5	104.0	9.0	8.0
S2	62	56.0	30.0	5.0	5.0

Table 5 Core fiber size measured from each part of hemp stem.

Sex of plant	Part	Width (µm)	Length (mm)
Male	Top	22.58 a	0.6548 b
	Middle	22.80 a	0.6728 ab
	Bottom	22.85 a	0.7072 a
Average		22.74	0.6783
Female	Top	18.53 a	0.5381 a
	Middle	16.33 a	0.5638 a
	Bottom	18.53 a	0.5742 a
Average		17.71	0.5587
Total average		20.23	0.6185
CV%		8.4	4.5
F-test	Sex	**	**
	Part	ns	*

3. Effects of sowing date on growth and development

3.1 Hemp flowering under natural photoperiod

The results of flowering time in 2002 and 2003 shown the sensitivity of hemp to the natural day length. In 2002 was the first time to observe the flowering of hemp under natural climate. From two sowing date in 2002, a time of seed set was in December. The repeated experiment was done in 2003 at Chiang Dao site with 2 sowing date and with temperate hemp from Germany. Hemp from Germany is very sensitive under natural climate and day length in Thailand. It could grown with completely life cycle within 77 days after sowing (Fig 22.).

Thai hemp show more detail in flowering pattern of development from S1 and S2 in 2003 that 2 sowing dates were developed at the same time of reproductive growth. In September 10th male flower occurred, October 10th was a starting of seed set and November 10th was endosperm filling when the seed enlargement was visible.

The flowering of hemp were recorded from 4 sowing date in 2004 at QSBG site where hemp planted on 27th July (S1), 21st August (S2), 13th September (S3) and 15th October (S4). At S1, S2 and S3 the stage of seed set occurred on late November to early December (Fig. 23) but there was late in S4 due to the late sow time. Male flowering started on September and seed set start on October. Seed enlargement or endosperm filling started on November. Seed ripening stage was in January, 2005.

The phenological development recorded from three years was stable over the season. The flowering time occur after October but degree of development or phonological changed from vegetative to reproductive was difference. As in S4 at QSBG site in 2004, the flowering period came early at late planting. Thus the climate and photoperiod at planting time was able to induce the photoperiodism in Thai hemp, that will discuss later.

3.2 Plant height and diameter

In 2003, plant height and D_{10} in sowing date 1 (May 10^{th}) were measured until 20 weeks after planting and sowing date 2 (July 10^{th}) was measured until 12 weeks after planting (Fig. 22). Both sowing date was terminated because of time of seed production. The average height at the end were 419.23 and 293.10 cm in S1 and S2, respectively. D_{10} were 17.03 and 17.39 mm in S1 and S2, respectively. The variation of plant height and diameter in hemp population was demonstrated by the error bar of standard deviation on chart. High variation occurred when plant was higher. Stem height and diameter of the different sowing date was demonstrated in Fig. 24. At the end of season plant height showed the different height while D_{10} of S2 can reach to D_{10} of S1.

For the effect of climate on plant height and diameter in 2003, the average temperature was 26.5 ºC in October then decline during November and December (Fig. 4). At this time plant height and diameter of both S1 and S2 were decline growth rate as they were in stationary phase (Fig. 24). The average temperature in 2004 was 26.3 ºC in October and 25 ºC in November (Fig. 5) the same phenomenal occur in S1 to S4 (Fig. 25). The different of maximum and minimum temperature were same trend as average temperature along the year. Thus the different height at final stem length should not direct effect from temperature.

For the effect of rainfall, the maximum rainfall in 2003 was on October for 315.8 mm and in 2004 was on September for 371.4 mm (Fig. 4 - 5). Comparing of plant height of S2 in 2003 and S1 in 2004 which grown at nearly time, S2 in 2003 was 294 cm while S1 in 2004 was 197 cm and D_{10} were 17.39 and 11.95 mm, respectively. In 2003 hemp grew better than in 2004, thus the exceed rainfall in 2004 might reduced growth of hemp.

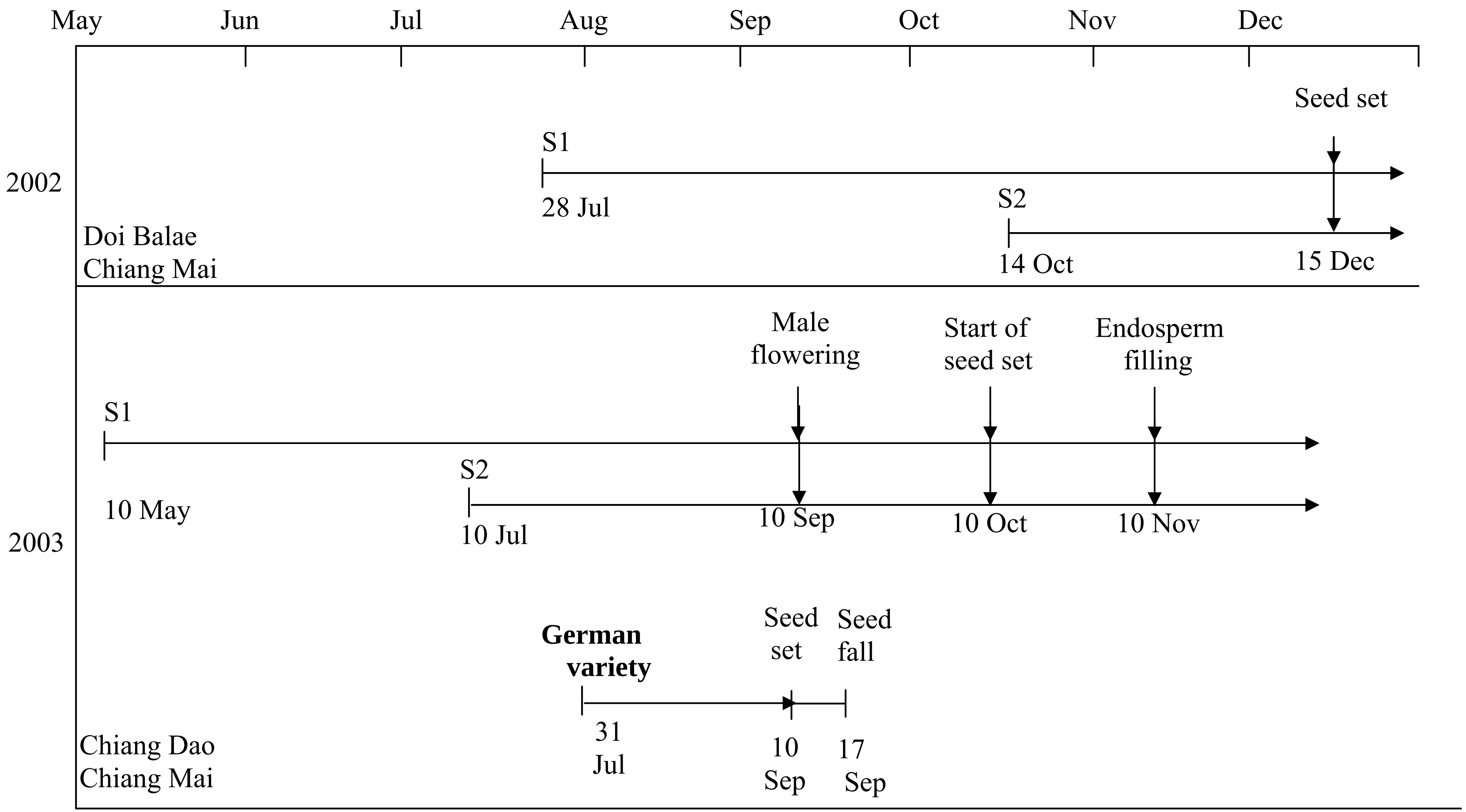


Figure 22 Hemp flowering time in Chiang Mai province, Thailand from 2002 to 2003.

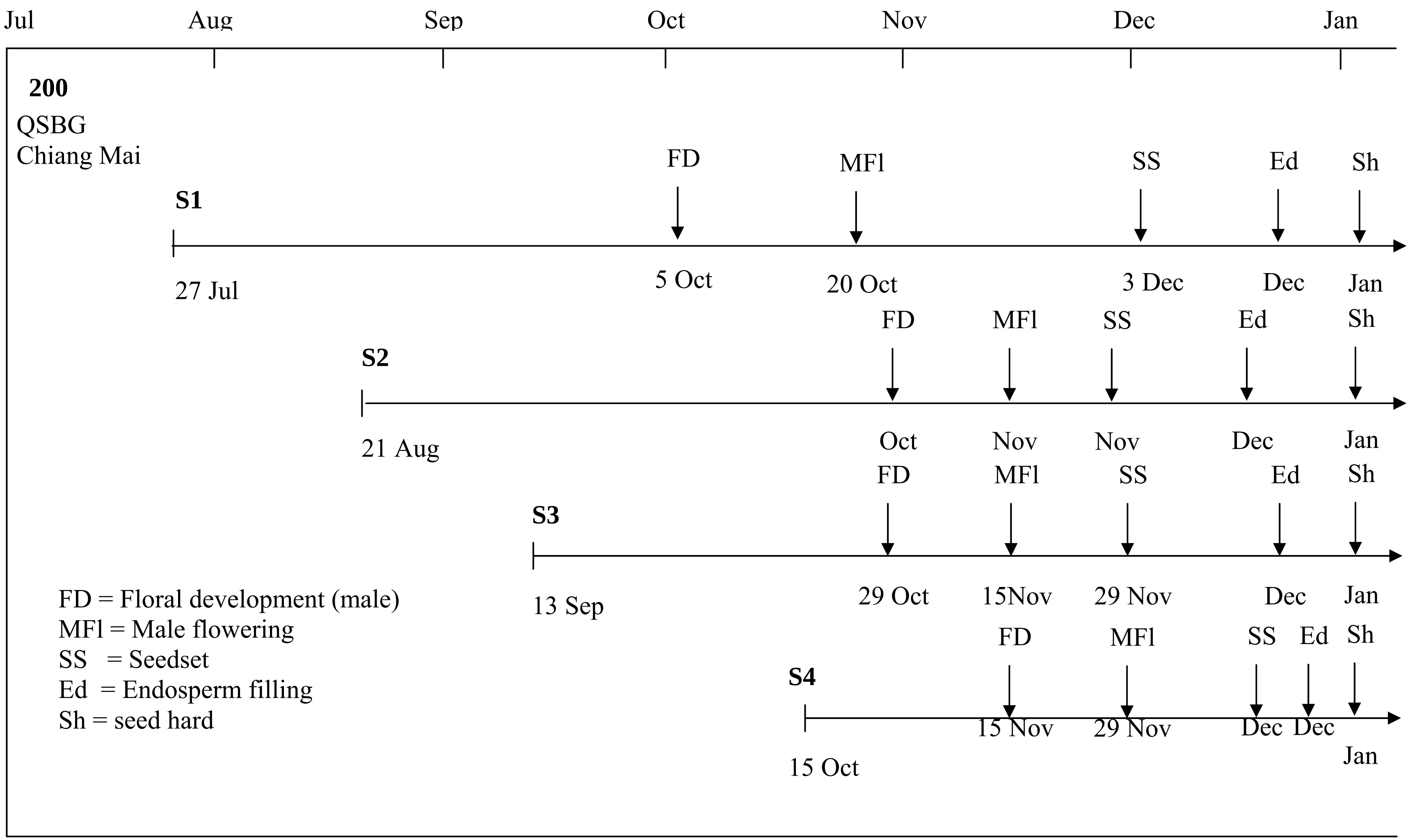


Figure 23 Hemp flowering time in Chiang Mai province, Thailand in 2004

The plant diameter had stop before plant height had terminated (Fig. 24). D_{10} of both sowing date was less different which could be the influence of plant density that control the population and growth direction in the horizontal area. The density in this experiment was carried between 20 - 30 plant.m^{-2} for all treatment, while many of research in hemp tried to increase density for more than 100 plant.m^{-2} (Lissen and Mendham, 2000; Lisson *et al*., 2000c; Struik *et al*., 2000). Thus the difference plant height should not from the effect of population in this experiment.

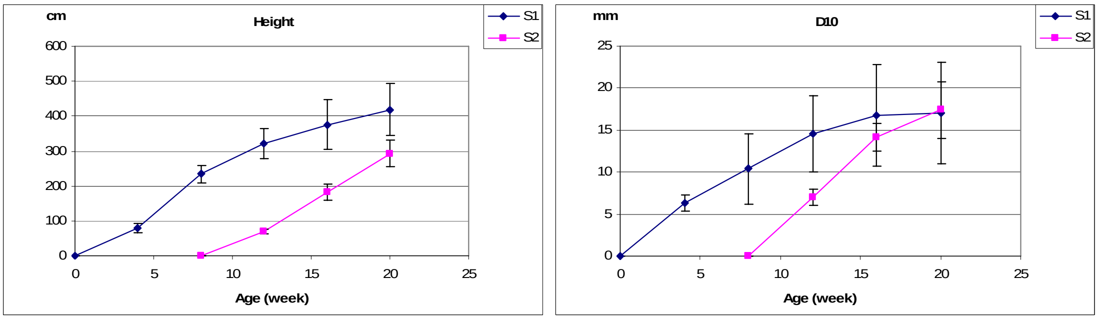


Figure 24 Height and D_{10} of S1 and S2 hemp grown in Chiang Dao in 2003; standard deviation shown as error bar.

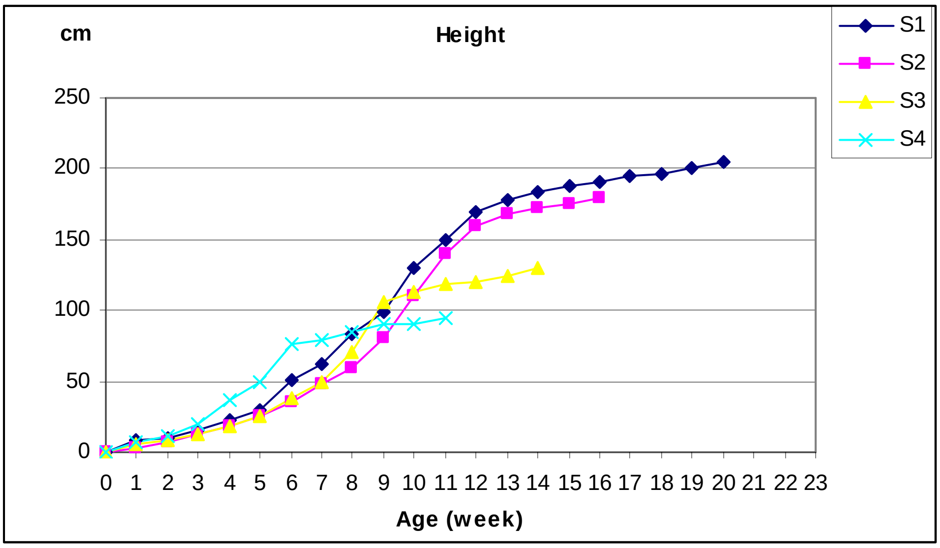


Figure 25 Height of hemp plant from 4 sowing date in 2004 at QSBG

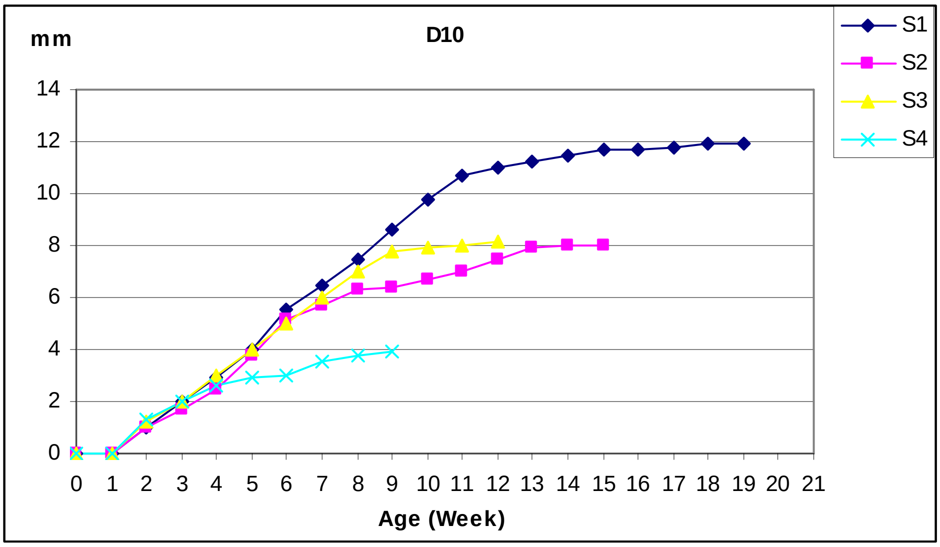


Figure 26 Average D_{10} of hemp 4 sowing date in 2004 at QSBG.

Average stem height at maturity were decline from 205.00, 180.00, 130.00 and 95.00 cm and D_{10} decline from 11.95, 8.17, 8.00 and 3.90 mm from S1 to S4, respectively (Fig. 25-26). When hemp grew to flowering stage, stem growth stopped as occurred in sunn hemp (*Crotalaria juncea* L.). The effect of sowing date of sunn hemp which have short-day flowering, responses as same as hemp. Delays in planting will shorten the growing season and could result in lower stalk yield (Cook *et al*., 1998). Stem height in 2003 and 2004 was declined when planting date was delay. Thus, the high possibility of yield of Thai hemp was decrease at late planting date. This had reported in temperate hemp that final stem length was strongly and positive related with stem yield (de Meijer and Keizer, 1994).

For stem diameter of hemp in 2003, 2 sowing date can reach to the same average stem diameter at flowering time (17.03 mm in S1 and 17.39 mm in S2). While stem diameter in 2004 declined in each delay planting date (11.95, 8.17, 8.00 and 3.90 mm from S1 to S4, respectively). Although it was significant effects of plant population on basal stem diameter but all treatment in 2003 and 2004 were grown at nearly plant density. This result was obviously difficult to conclude due to basal stalk diameter was more influence on environmental effect (Cook and Scott, 1998). A possible reason that the diameter in 2004 declined, plant stop its grown after flowering because of the shorter growing season.

Average height and diameter from 4 sowing dates in 2004 at QSBG site were sigmoid curve (Fig. 25 – 26). Thus A logistic equation (1) was fitted to the periodical measurements of stem growth of plant (Jean, 1984; de Meijer and Keizer, 1994).

$$G(t) = U / (1+ e^{M(T-t)}) \quad (1)$$

Where $G(t)$ = stem length at day t (cm)

U = maximum length of stem length (cm)

M = slope coefficient (day^{-1}) at point T

T = curve inflexion point (day) at 50%

Data were fitted by Levenberg-Marquardt method base on Multi-Logistics Equation using program PlantPV (Fig. 27-28) (Chuai-Aree *et al*., 2006).

The parameters from stem height and diameter in 2004 were characterized by the slope coefficient (M), inflexion point (T) and upper asymptote of a sigmoid curve (U) fitted to the measurements of stem height and diameter. When plant were grown at delay planting date and time of flowering become a factor to stop plant growth, late planting time reduced rate of maximum stem length as the decline of U. The decline of T (curve inflexion) and M (slope coefficient) means hemp spend less time to stop their growth which implied that changing their development from vegetative to reproductive phase was faster in each delay sowing date. The decline of parameters value was occurred both in height and diameter (Fig. 29-30).

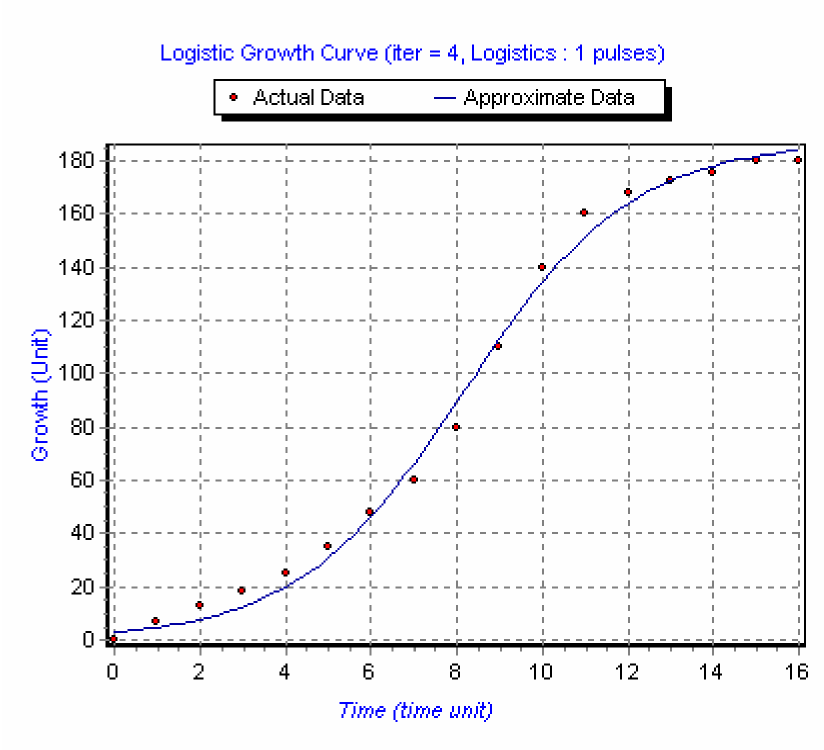


Figure 27 Logistic growth curve from curve fitting of plant height, sowing date 1

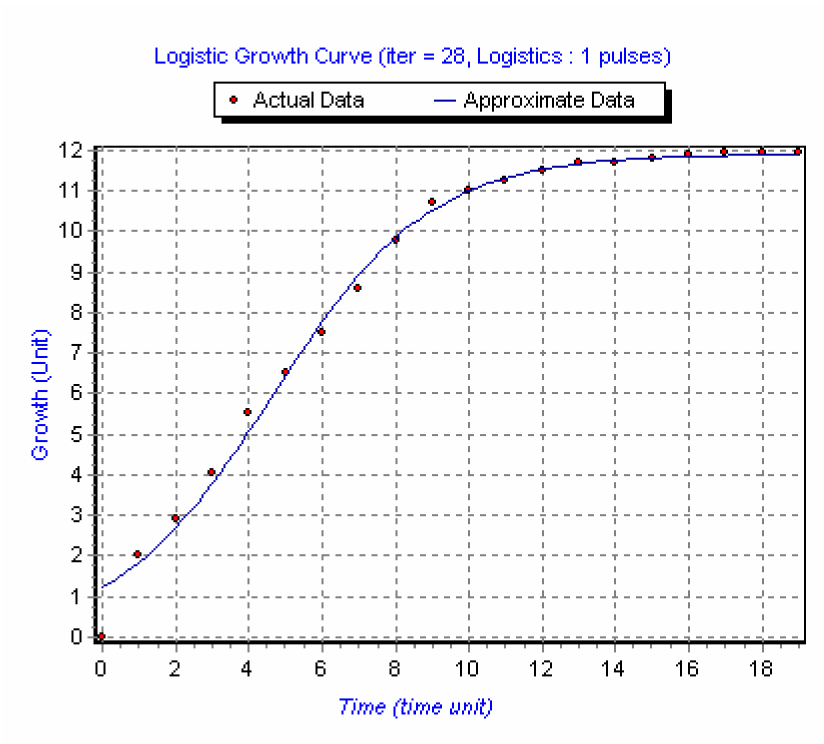


Figure 28 Logistic growth curve from curve fitting of plant diameter, sowing date 1

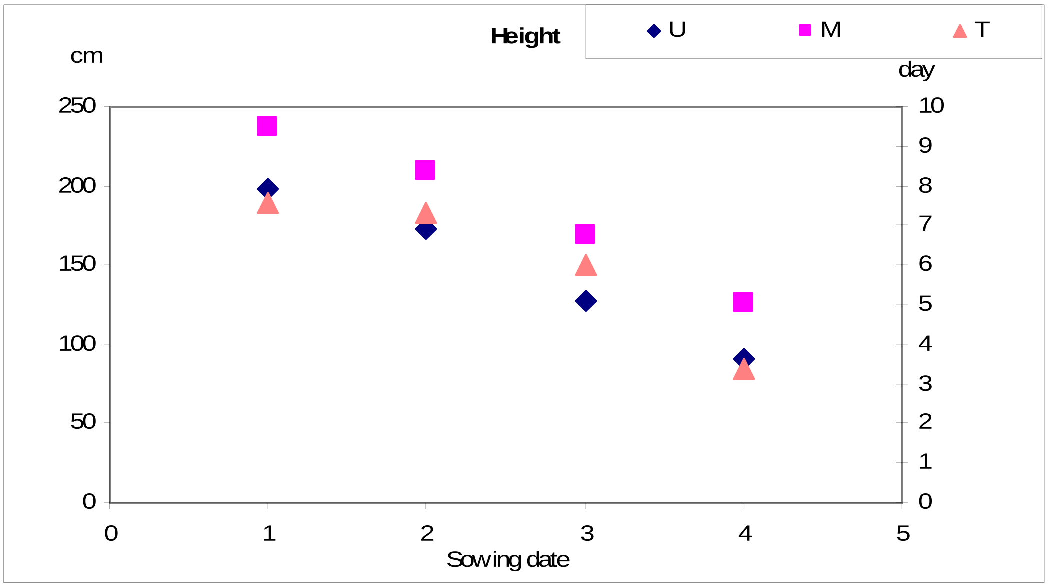


Figure 29 Parameters of plant height from the calculation from four sowing date in 2004

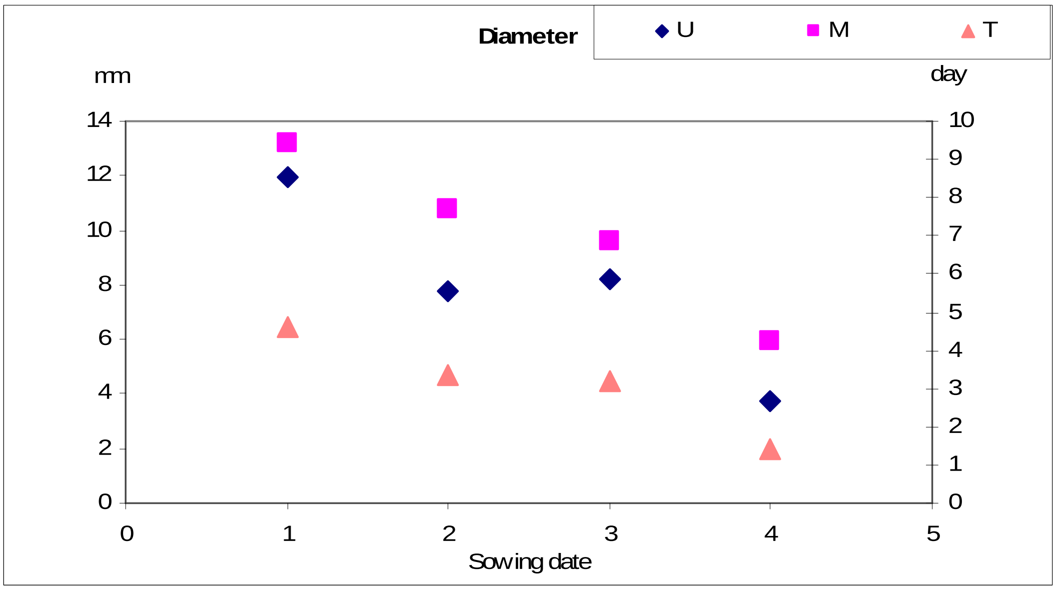


Figure 30 Parameters of plant diameter from the calculation from four sowing date in 2004

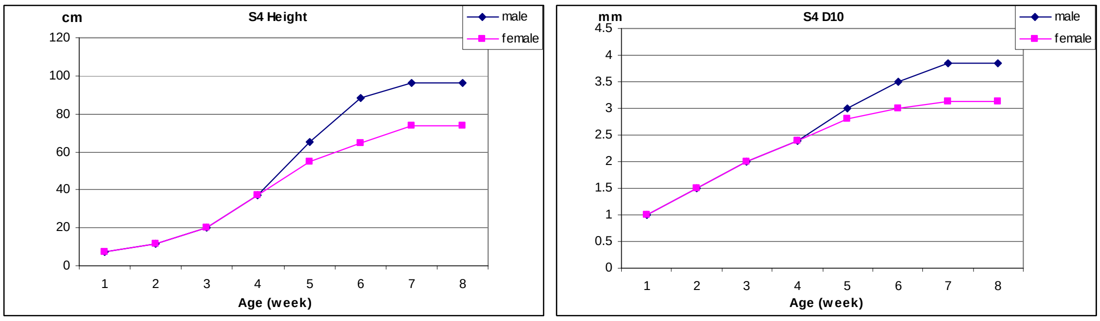


Figure 31 Average height and D_{10} between male and female plant from sowing date 4

On the trial of S 4 final stem length, male plants exceeded females in final stem length by about 20 cm (Fig.31). This height difference among male and female plant was a typical as in temperate hemp and as same as recorded that male plant was slender than female plant.

3.3 Rate of leaves appearance and phyllotaxis

According to many reported (Schaffner, 1926; Mediavila *et al.*, 1998) when hemp grow up leaves orientation was change from opposite to alternate. The termed here define this leaves orientation as spiral according to the meaning of alternate by Allaby (1992) that mention leaves are not opposite to each other on the axis, but arrange singly at different heights. While the term of spiral is mention the position that borne at different levels along the axis, in an ascending spiral (Allaby, 1992; Croft, 2005).

The phyllotaxis changed in hemp was first reported in the classic work by Schaffner (1926) in which the plants in continuous light all changed from the opposite to the spiral (alternate) phyllotaxis at the 7^{th}, 8^{th}, or 9^{th} leaf node, without noticeable change in leaf character. The phyllotaxis changed had evident that the stimulus of light or rejuvenation by continuous light cannot be much below the fourth node.

The phonological record of S1 to S4 by phyllotaxis changed from opposite to spiral was at 5.86 to 6.33 leaves pair. This phonological character was use as a signature when the reproductive growth had start as report by many researchers (van der Werf *et al.,* 1995b; Mediavilla *et al*., 1998; Lissen and Mendham, 2000). The result of leaves phyllotaxis of S4 during juvenile phase was opposite and leaves at the inflorescence were the spiral as ordinary occurred in this species. The leave orientation of S4 was not changed during juvenile phase. When plant developed to flowering period, dense and short internode appeared instead of opposite leaves at the terminal shoot. The orientation of leaves at shoot apex was spiral because of floral development. This phenology was occurred as the flowering of German variety that very sensitive to photoperiod in Thailand. Thus it might possible that sensitivity of phyllotaxis changed was less than the sensitivity of changing the vegetative to reproductive according to the photoperiodism.

The relative among leaves appearance and plant height of S1 to S4 showed that leave appearance was increase at time of flowering (pointed by the arrow in Fig. 33), when the stem height was decrease. This effect was influence of changing the growth pattern from vegetative to reproductive when the energy from photosynthesis was locate to reproductive organ (Kozlowski and Pallardy, 1997).

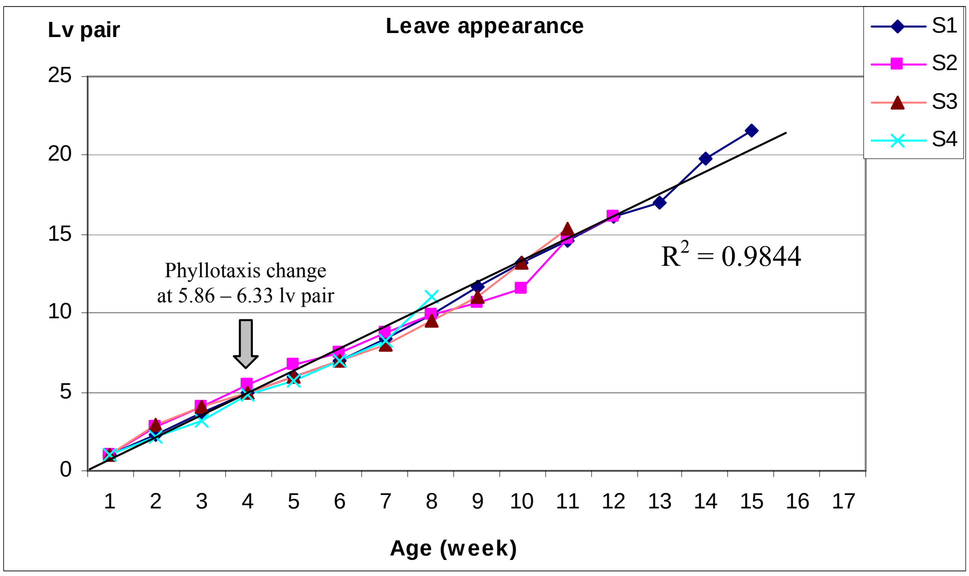


Figure 32 Phyllotaxis change and number of leave appearance

Linear equation of leave appearance of hemp 4 sowing date in 2004 was

$$Y = aX + b$$

S1 $\quad Y = 1.3986X + 0.0981 \qquad R^2 = 0.9844 \qquad (2)$

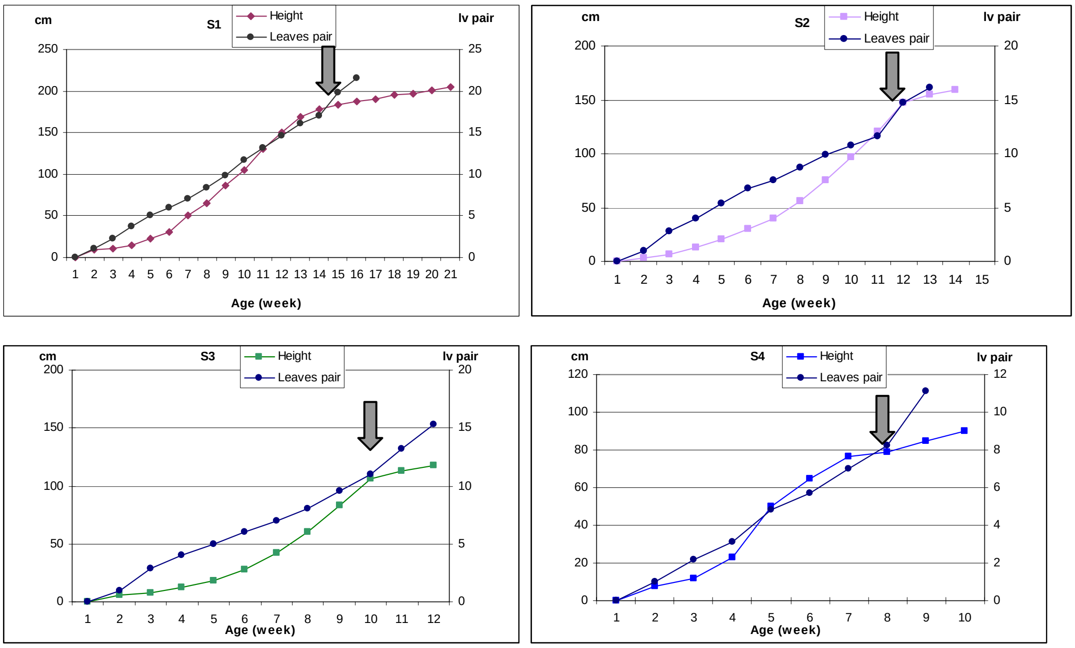


Figure 33 The relationship among number of leaves pairs and height of hemp from 4 sowing date in 2004.

4. Floral development of hemp

From the result of flowering time in 2002 and 2003, the intensive record of floral development was investigated in 2004 at QSBG. Due to a different longevity of growing season and developmental stage cause by different sowing date, the code and abbreviation in this report was base on the stage of development in Table 6.

4.1 Individual floral development

The single floret development record was shown in Fig 34. After the vegetative development, the reproductive development started from the signal of leaves by reducing its size and starting of stem elongation. The unidentified plant can be separated into male and female after 10-20 days from the beginning of floral development. Male flower was identified by the dense group of floret on the axillary bud. Later 10 days can identified clearly by the appearance of the floret enlargement and the amount of floret number. After floret was mature, a time of flowering was start within a week. Pollination of male inflorescent spends 2-7 days. Then the next floret of the same inflorescent pollinated continuously.

Female plant was identified by the appearance of floral bract at the axillary bud on main stem. At this stage, the morphological characteristics of apical leaves was reduced their size and shape as awl. Ten days later can see more detail of floret by the tiny structure of floret which called bract. The florets bloom for 2-7 day and within 2-5 days the fertilization has started. Stigma might be white (translucent) or red and its turned to brown and wilt after fertilization. At early seed development, the persistence stigma still appear. Then there was a month of endosperm filling and ovule enlargement. The seed still soft and succulent and its need the protection organ by female bract with the resinous glandular trichome. Then seed coat become hard and the time of senescent was noted when bract dried. This stage was called seed ripening which take a mount in the field. Conversely, male plant start deteriorate, leaves drop and dry.

4.2 Field floral development

Field floral development was carried out base on S1. Field floral development were notice by the elongation of stem. At this stage the distance between the opposite petiole of leave pair was distingue and increase. Then the pair of opposite leaves was changed, thus leaves orientation changed from opposite decussate to spiral. Then axillary's floral bud appear a month after. This stage floral bud was not clearly identify sex except under microscopy. Then a month later, the first mature floret was begun and the pollination of a plant continuously for 2 weeks for individual plant and per month for population. After pollination male plant was start deteriorate.

Female plants started to develop at same time of male plant but the tiny floral structure made a difficult notice with naked eyes. Female plant was identified clearly at stage of seed set or endosperm filling which presented after a month of male development. Female plants took a month for endosperm filling and a month for physiological maturity. At physiological maturity, bract margin dried and seed easily fail from the floret. There was 3 month from the beginning of floral development to the harvest time. The conclude chart for field floral development from plant sowing date 1was shown in Fig. 37.

The effect of sowing date on flowering time and longevity of floral development in four sowing date were demonstrated in Fig. 38. The period of vegetative growth was from sowing date to time of first male floret appearance, male flowering period was from first male floret appearance to 90% pollination, female flowering period was from first detected of female floret to a visible seed. Seed development period was from the first seed appearance to seed maturity. The longevity of vegetative period was depended on how early of sowing date started. The long vegetative period spend, the high stem elongation and the long reproductive phase occur.

Table 6 Abbreviation and definition on floral development of hemp

		Abbreviation		Definition
		S	sowing time	
		Vg	Vegetative growth	Growth time from sowing time to the appearance of fist male floret
Stage 0		Un		Unidentification of sex on plant
Stage 1	FI	Flowering primordia		Sex nearly indistinguishable
		Male		
Stage 2	FD	Floral bud enlargment		
Stage 3		Anther development		Time from anther initiation to mature
Stage 4		Early matirity		Anther mature but not pollination
Stage 5	FL	First pollination		
Stage 6				50% pollination
Stage 7				95% pollination
Stage 8				Leaves drop
Stage 9				Stem deterioration
		Female		
Stage 1	FI	Floral bud appearance		
	FD	Floral bract appearance		
Stage 2	FL	Flowering		Styles on first female flowers
Stage 3	Fer	Fertilization		Note by the wilting of stigma
Stage 4		Early seed development		Enlargement of the floret
Stage 5	SD	Seed development		Endosperm soft and succulent
Stage 6	SM	Seed maturity		Starting of seeds hard
Stage 7	SR	Seed ripening		Bract dry

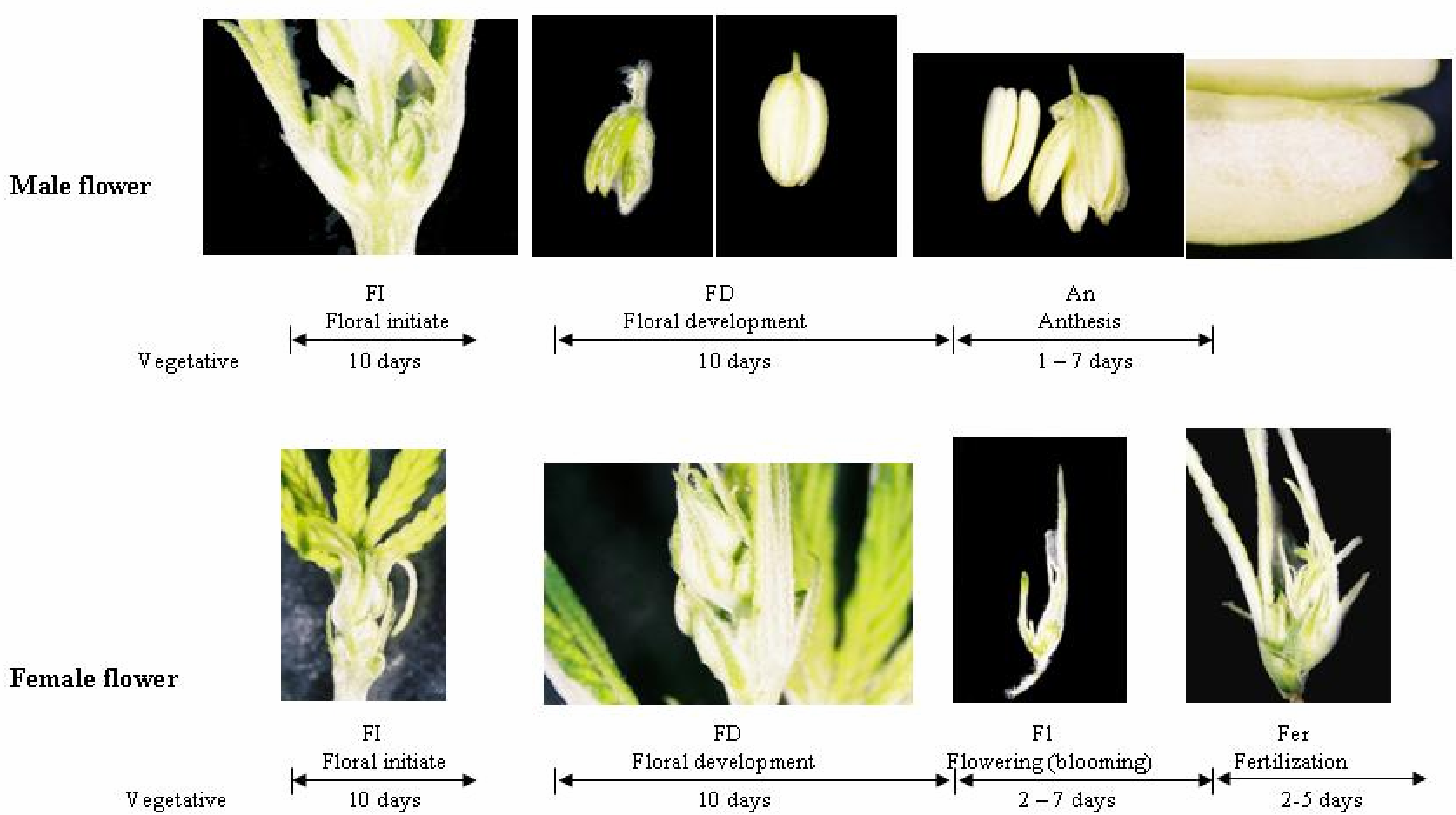


Figure 34 Pattern of floral development during reproductive growth

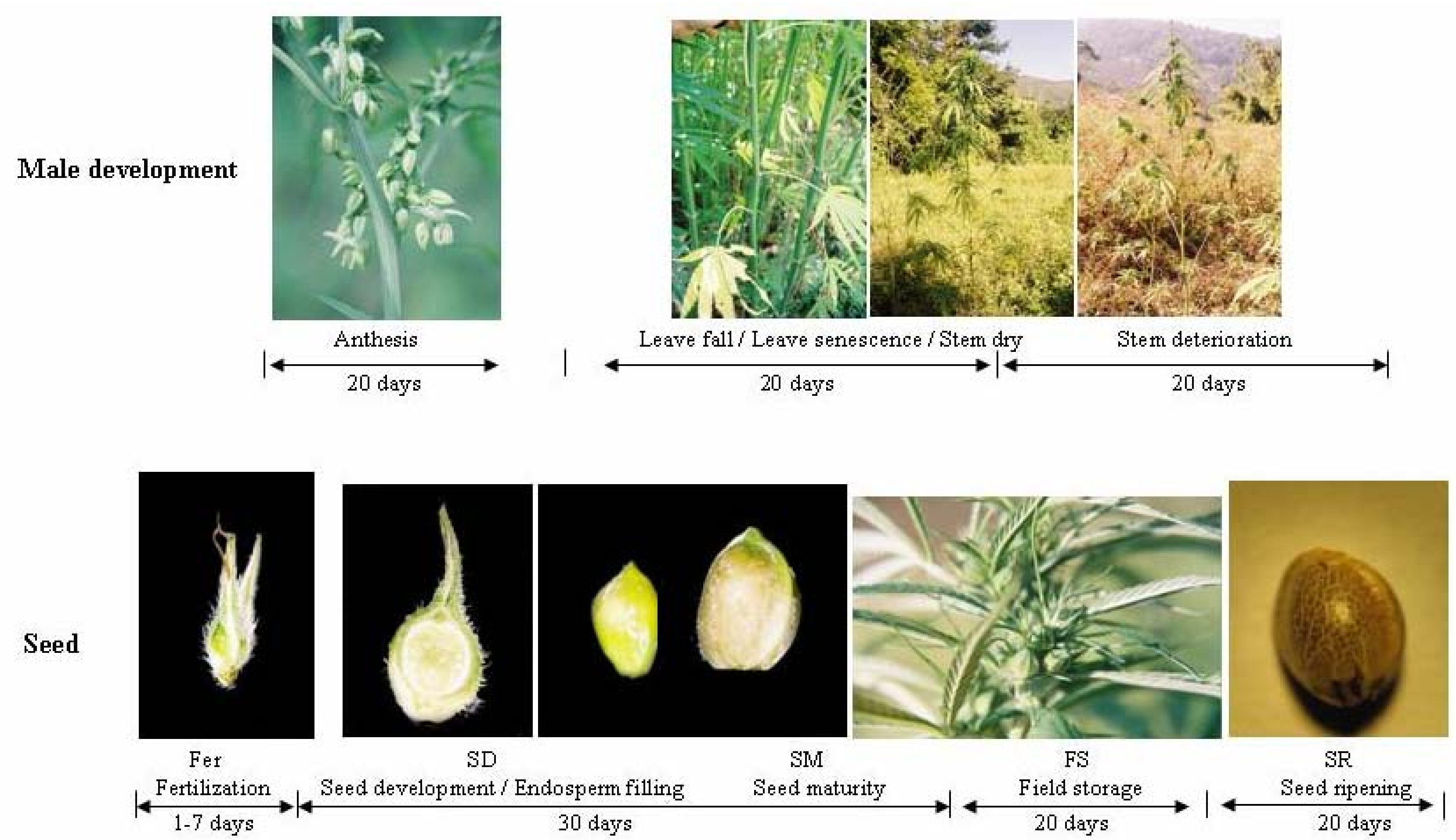


Figure 35 Pattern of Seed development and stem deterioration

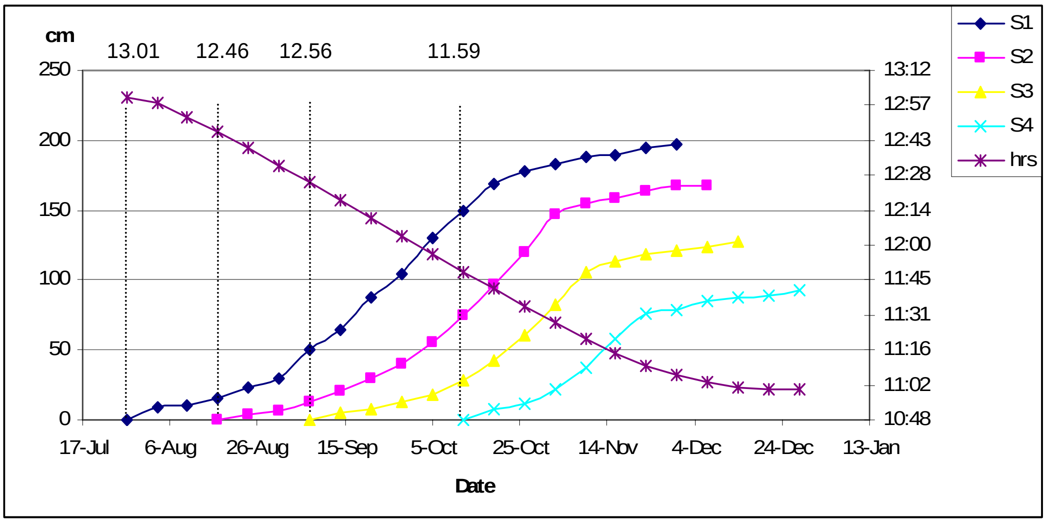


Figure 36 The relative daylength to the stem height of hemp in 4 sowing dates.

The difference sowing date of Thai hemp had an effect to both vegetative and reproductive phase. It reduced period of vegetative and induced the faster reproductive phase and shorten this time. Daylength that induced the flowering of Thai hemp was approximately 11 - 12 hrs. Thus the daylength related to the hemp growth and development (Fig. 36 - 37).

At delayed planting, the initiative daylength become shorter. This result in stem elongation time from planting to inflexion point was decline from 12, 11, 9 and 6 week, respectively (Table 7).

Table 7 Daylength at time of planting hemp

Sowing date	Daylength at planting (hrs)	Daylength at inflexion point (hrs)	Vegetative period* (week)
S1	13.01	11.42	12
S2	12.46	11.27	11
S3	12.26	11.21	9
S4	11.59	11.10	6

* the vegetative stage was marked from planting date to date at inflexion point

The research of hemp to photoperiod had investigated in temperate region but less in tropic. The difference among two regions is the climate and the variety of hemp. Thus, it is difficult to compare the photoperiodism of each variety because the difference of temperature and photoperiod of each location. The photoperiodism of hemp varies from 9 hrs (Heslop-Harrison and Heslop-Harrison, 1972) to 14 hrs (Borthwich and Scully, 1954; Lissen *et al*., 2000a), thus the thermal time requirement (basic vegetative phase + photoperiod induced phase) became a tool to explain the phenological changed by Major (1980).

The respond to photoperiod was described by Lissen *et al.* (2000a), therefore the vegetative phase of development from emergence to floral initiation is broken down into a temperature dependent basic vegetative phase (BVP) and a daylength-dependent photoperiod induced phase (PIP). The flowering response to photoperiod in hemp was explained by daylength or thermal time. Nelson (1944) pointed in 2 varieties of hemp from Portugal, thermal time duration varied little between the lower 2 temperature (355 and 378 °Cd above 1 °C respectively) but increased dramatically under the highest temperature regime.

The flowering response to photoperiod for the 2 hemp cultivars, Kompolti and Futura 77 were typical for a quantitative short-day plant (Heslop-Herrison and Heslop-Herrison, 1969). Lesson *et al* (2000a) pointed that the sensitivity of flowering in hemp to photoperiod has a number of implication in the cultivation of this crop, especially at low latitudes. The limitations associated with the photoperiod sensitivity of hemp are expected to become more significant at lower latitudes (shorter daylengths). The parameters quantifying the flowering response of hemp to photoperiod by estimate effect of temperature encounter with other environmental dataset will useful in predicted phenology (Lissen *et al*., 2000c).

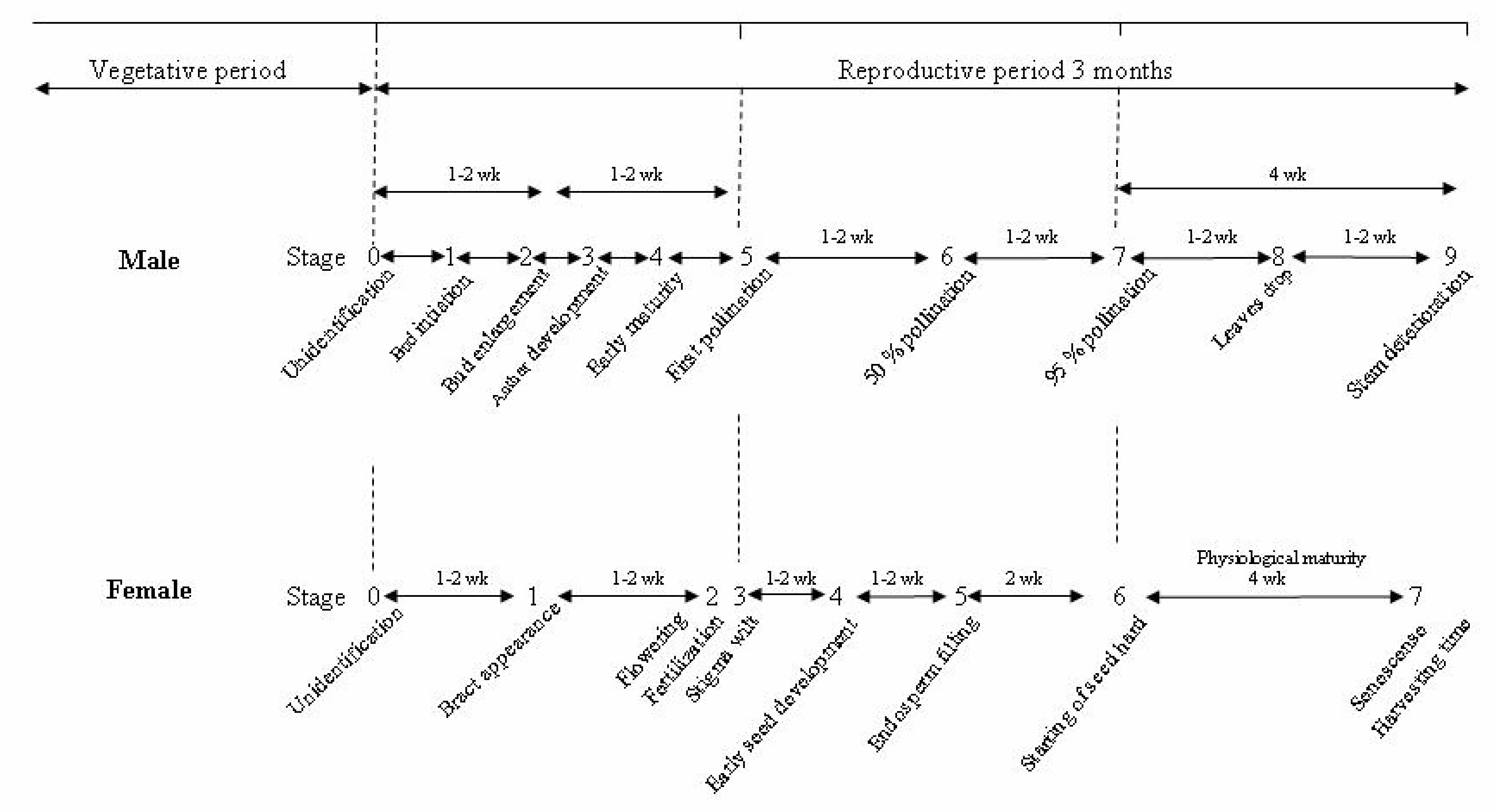


Figure 37 Stage of floral development of hemp in 2004, QSBG Thailand

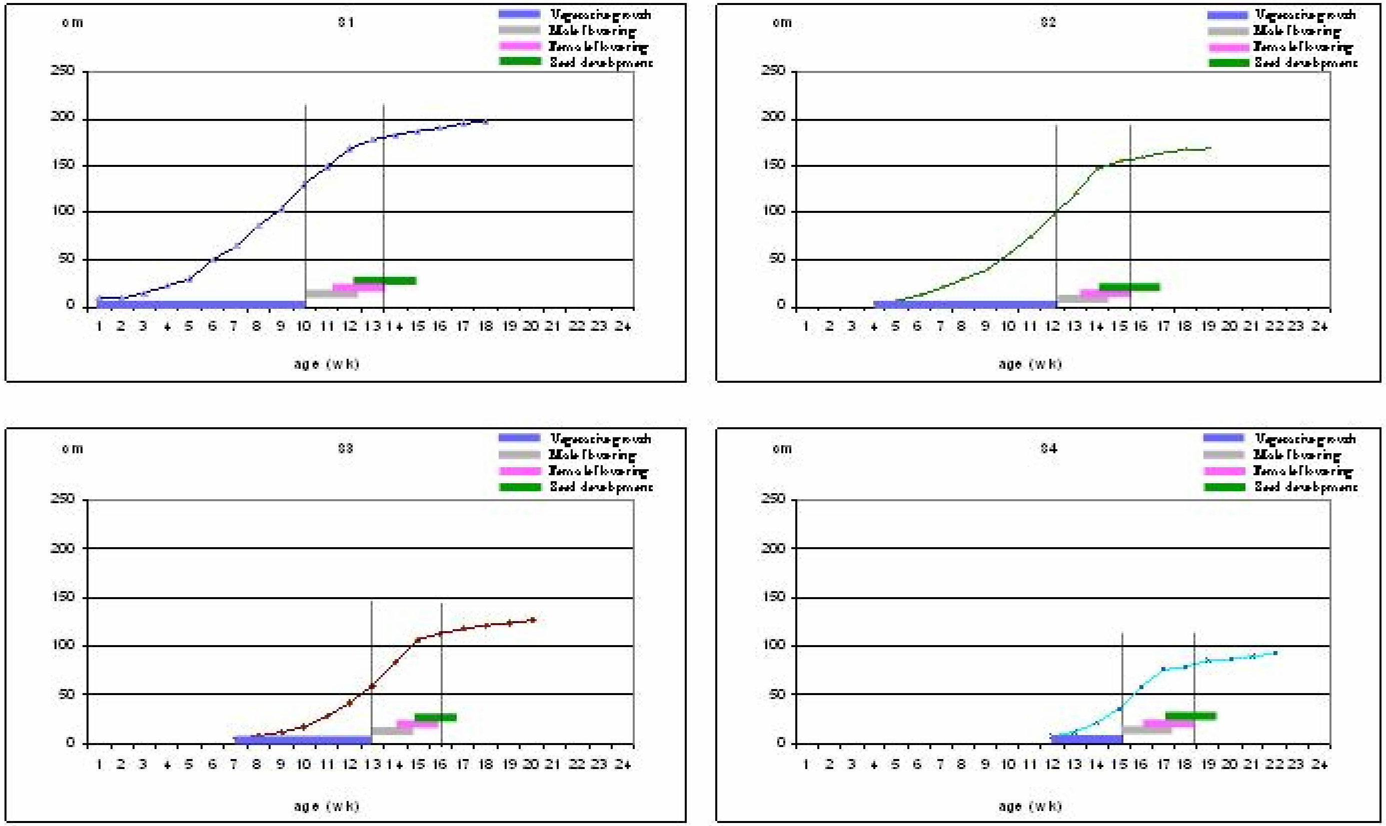


Figure 38 The relative plant height and field development of hemp from 4 sowing date in 2004, QSBG

5. Fiber properties

5.1 Stem growth

Hemp was grown in July when it was rainy season. The average stem height in this experiment was 165.98 cm with 8.24 mm stem diameter at 65 days after planting (harvest 1), measured at 10 cm height above the soil (D_{10}), and 267.35 cm height with 11.15 mm D_{10} at 120 days after planting (harvest 2). Male and female plants were separated at harvest 2. The average height of the male stem was 274.35 cm which was slightly higher than the mean value of the female stem with 260.35 cm. The average diameter (D_{10}) of the male stem was 10.29 mm while the female stem had stem diameter of 12.02 mm. The average plant density was 24 plant m^{-2} at harvest 1. After sex was identified at harvest 2, the ratio of male and female plant was 13.6 : 10 in a square meter area (Table 8). The detail of plant and yield was discussed later in topic 6. Fiber yield.

Table 8 Stem growth for each treatment of fiber testing.

Day after planting	No. of Plot	Height (cm)	Diameter (mm)	Density / m^2 (plants)	Stage of development
65 (Harvest 1)	10	165.98 $\pm$ 14.90	8.24 $\pm$ 0.71	24.00 $\pm$ 5.87	Vegetative growth
120 (Harvest 2)	10	267.35 $\pm$ 7.25	11.15 $\pm$ 0.92	23.60 $\pm$ 2.41	Reproductive growth
120	5	274.35 $\pm$ 11.68	10.29 $\pm$ 1.14	13.60 $\pm$ 4.28	Male
120	5	260.35 $\pm$ 11.68	12.02 $\pm$ 1.14	10.00 $\pm$ 4.36	Female

5.2 Bast fiber fineness

5.2.1 Airflow method

The Airflow method was applied from wool fiber fineness testing. Usually the pressure input to fiber mass is a pressure that move the water in a column to a distance of 120 mm. More fineness fiber, less air flow out because fine fiber have large area.

In this experiment, Thai hemp showed extremely fine when measure under pressure of 120 mm of water column. There was no measurable result from the top part of the stem from harvest 1. As fiber extremely fine, the area of fiber mass was high until air hardly pass through until immeasurable. Thus more pressure input at 200 (results labeled with an index: $FBAI_{200}$) and 250 mm (results labeled with an index: $FBAI_{250}$) of water column were applied to all samples (Fig. 39). FBAI refer to FIBER Bastfaser Airflow Index which applied as a unit of fiber fineness in Airflow method instead of µm due to result from Airflow method was indirect which calibrated the air that flowed though the fiber mass (Müssig, 2001). The pressure input to fiber were label with subscription. The finest fibers and bundles were present in the top part of the stem and the coarsest in the bottom section. Fiber fineness from pressure input at 200 and 250 mm showed no differences between the middle and bottom part. Fiber and bundle fineness between decortication methods were 14.23, 17.55, 23.16 $FBAI_{200}$ from fresh decortications and 14.75, 16.24, 21.97 $FBAI_{200}$ from dry decortication; top, middle, bottom, respectively (Fig. 40). Thus, there was not different in fiber fineness among the difference decortications method.

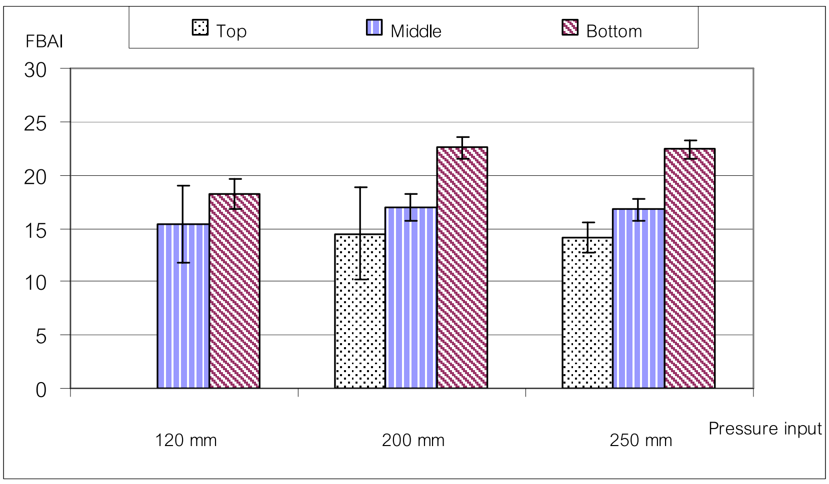


Figure 39 Average Airflow values (FBAI values) of chemical separated Thai hemp fiber and fiber bundles (harvest 1) at different pressure inputs (120, 200 and 250 mm).

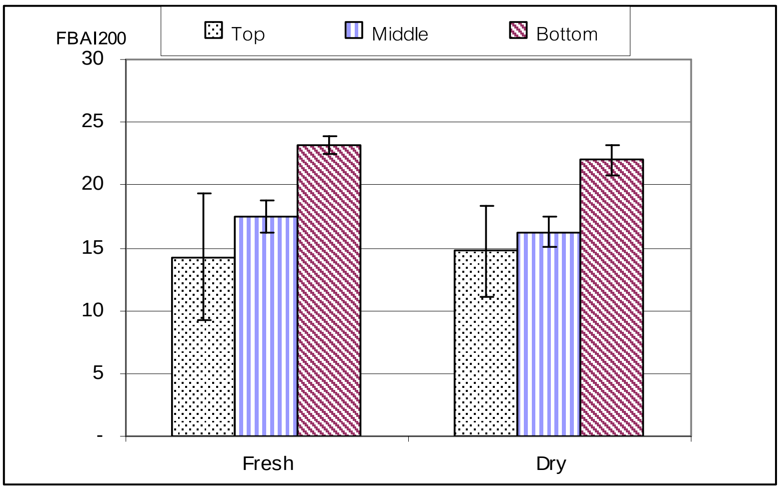


Figure 40 Airflow values ($FBAI_{200}$) of hemp fibers from fresh and dry decortication

Fiber from the top, middle and bottom of the stems from hemp harvest 1 were 14.5, 16.9, 22.6 $FBAI_{200}$ respectively, which is finer than samples from harvest 2; 17.7, 24.1, 26.6 $FBAI_{200}$, respectively (Fig. 41). There were no significantly different between male and female fiber fineness. Fiber and bundle fineness between sexes of plant were 18.28, 23.68, 26.08 $FBAI_{200}$ from male and 17.04, 24.43, 27.08 $FBAI_{200}$ from females top, middle, bottom, respectively. However, there were significantly differ among harvest 1 and 2 which fiber from harvest 1 was finer than harvest 2 in each part. The fiber fineness in male was slightly less than female but not significant different. The results showed indicated pressure input at 200 mm can applied to fine hemp fiber.

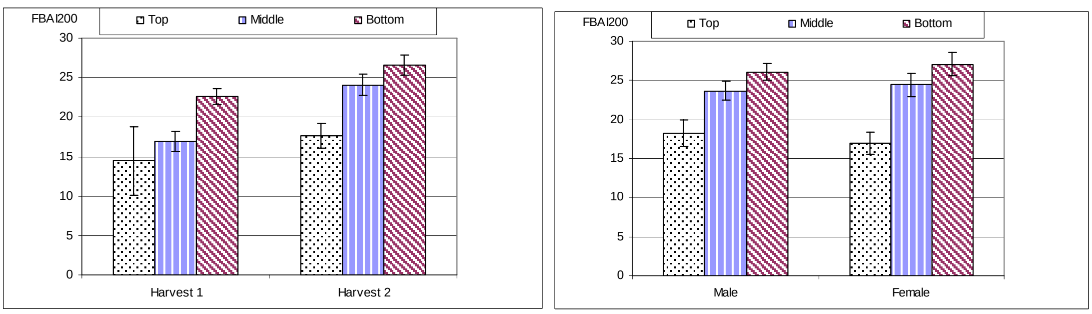


Figure 41 Average Airflow values ($FBAI_{200}$) of chemically separated hemp fibers and fiber bundles at a pressure of 200 mm for two harvest date and male and female plants (for harvest 2).

5.2.2 OFDA method

The OFDA method was applied to assess fiber fineness. The average fiber fineness from fresh and dry decortications were 14.08, 15.72, 17.48 and 14.88, 15.68, 16.90 µm from top, middle, bottom, respectively (Fig. 42). The fiber fineness of harvest 1 and 2 were 14.08, 15.72, 17.48 and 15.08, 18.52, 18.73 µm from top, middle, bottom, respectively. The fiber fineness of male and female were 14.9, 18.18, 18.36 and 15.26, 18.86, 19.10 µm respectively (Fig. 43). There was not significant different value of fiber fineness between fresh and dry decortications. The different fiber fineness was between harvest 1 and 2 at the middle part. Fiber fineness from middle in harvest 2 was almost equal to bottom part while it presented value between top and bottom at harvest 1. This indicated that uniformity of fiber fineness occur in middle and bottom part of stem when its growth to stage of flowering. The different fiber fineness among male and female was not found by OFDA.

Fiber and fiber bundle fineness according to the Airflow and OFDA methods presented similar result the same degree of fiber fineness on stem. They were coarse at the bottom and fine at the top. To evaluate the potential of using Thai hemp for textile applications produced by modern spinning techniques, the OFDA values of chemically separated hemp from trials described in this research were compared to hemp fibers which suitable for open-end spinning. The comparison of fineness of hemp fiber from Thailand with that of other hemp tested by OFDA is shown in Table 8. Thai hemp fiber was very fine when compared to Chinese hemp (17.4, 16.3 and 17.0 µm) and flax (15.3 µm) from chemical separation (Müssig *et al.*, 1998; Dreyer *et al.*, 2002).

The statistical analysis of fiber fineness from Airflow and OFDA were the same result. There was high significant difference among stem part and harvesting time. Compared with the OFDA, Airflow method did not provide information about the distribution of fineness for individual fiber or bundle. However, this method was very rapid as well as being highly reproducible (Drieling *et al.*, 1999). While OFDA consumed more time and gave the distribution of fineness. It required a smaller amount of fiber for testing. Thus, both testing methods can applied to Thai hemp depending upon the requirements of comparable standards to other data and conditions. Such as the amount of fiber, the number of sample that need to test and the existed data that need to compare. The comparison of Thai hemp to other commercial hemp in Table 8 was in the same standard of testing. Thus the fiber fineness was a high evident for comparison.

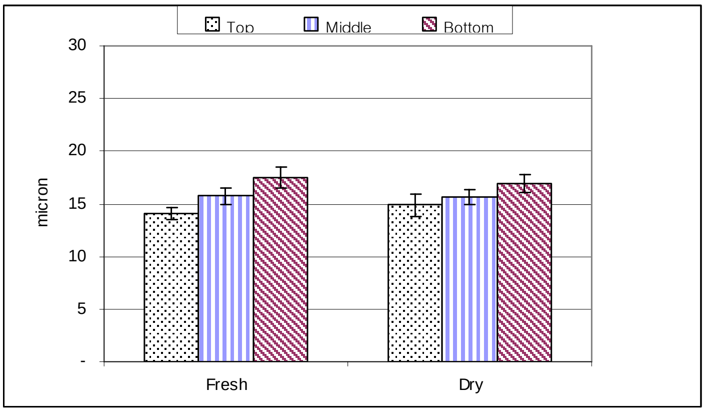
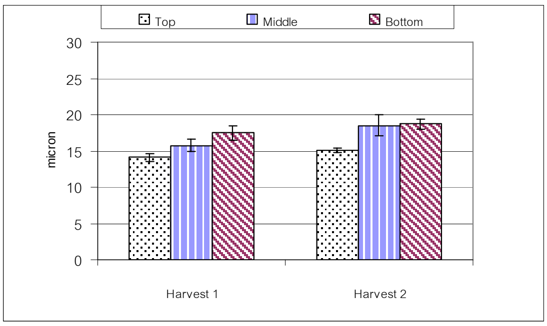


Figure 42 Mean values of fiber and fiber bundle width among fresh and dry decortication measured by OFDA.



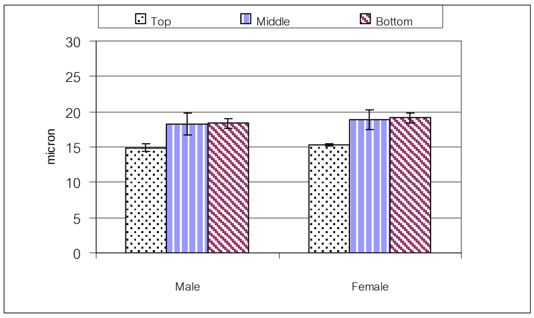


Figure 43 Mean values of fiber and fiber bundle width measured by OFDA for two harvest date and male and female plants (for harvest 2)

Most commercial hemp cultivation was carried out at high plant density from 200 to 300 plant m^{-2} (Lisson and Mendham, 2000; Lisson *et al*., 2000c; Struik *et al*., 2000). Thai hemp cultivation trials were carried out at low plant density at approximately 24 plant m^{-1}. A high density normally allows higher yield and improved fiber fineness. The results presented here show that Thai hemp produces fine hemp fibers at low plant density. How to improve both fiber yield and fiber fineness of traditional Thai hemp by increasing plant density to the level that allows the high yield but remain its quality. This should be investigated in the future.

5.3 Tensile strength

5.3.1 Stelometer method

The strength values of fiber-bundle collectives measured with the Stelometer was shown in Fig. 44. All samples had the highest strength in the middle part of stem as reported by Funder (1973), who describes this effect of the strongest fibers in the middle section for flax, hemp and jute plants.

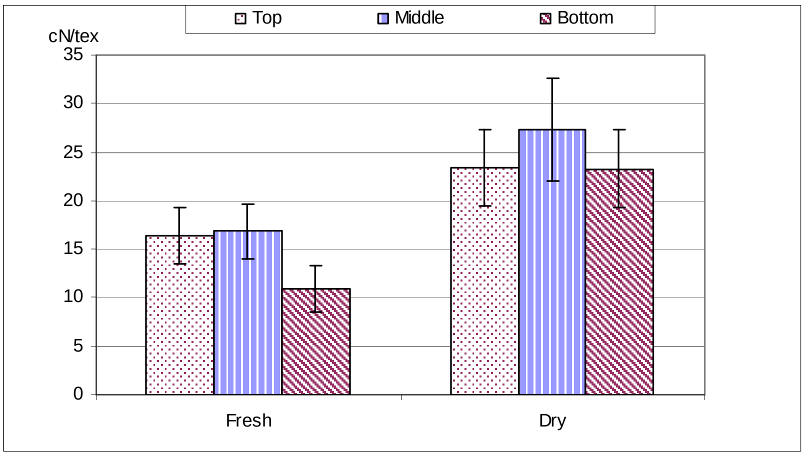


Figure 44 Hemp fiber collective strength measured with the Stelometer device, mean value for two decortication methods form harvest 1.

Table 9 OFDA results for different bast fibers (hemp and flax) with a quality level suitable for open-end spinning in comparison to Thai hemp.

	Mean Value in µm	Median in µm	Part<30µm In %	Part > 100 µm in %	Number of measured fiber bundles
2c/SE*	18.1	15.2	91.9	0.2	59,516
4c/SE*	19.1	15.2	89.8	0.5	63,471
HNF_A*	17.4	14.5	92.2	0.1	72,279
HTEX*	16.3	13.9	94.4	0.0	75,900
NTEX*	17.0	14.4	93.1	0.1	77,648
FLASIN*	15.3	13.2	96.9	0.2	89,031
OFDA values for Thai hemp fibers presented in this paper					
Th Fresh	15.8	13.1	95.0	0.2	54,527
Th Dry	15.8	13.1	94.8	0.2	50,767
Th harvest 1	15.8	13.1	95.0	0.2	54,527
Th harvest 2	17.4	14.3	91.7	0.3	55,727
Th Male	17.1	14.0	92.6	0.2	56,064
Th Female	17.7	14.5	91.7	0.3	55,390

* values given by Dreyer *et al*. (2002) for bast fiber with properties to be processed with modern cotton spinning equipment

2c/SE and 4c/SE = hemp fiber after steam explosion (Müssig *et al*., 1998)

HNF A = Chemically separated short hemp fibers from the HNF Company, China

HTEX = Chemically separated short hemp fibers from the Hemptex Company China

NTEX = Chemically separated short hemp fibers from the Naturetex Company, China

FLASIN = Chemically separate flax fibers from the Flasin Company, Germany (Dreyer *et al*., 2002)

Th Fresh = Chemically separated hemp from fresh decortication (age of 65 days)

Th Dry = Chemically separated hemp from dry decortication (age of 65 days)

Th harvest 1 = Chemically separated hemp from fresh decortication (age of 65 days)

Th harvest 2 = Chemically separated hemp from fresh decortication (age of 120 days)

Th Male = Chemically separated male hemp from fresh decortication (age of 120 days)

Th Female = Chemically separated female hemp from fresh decortication (age of 120 days)

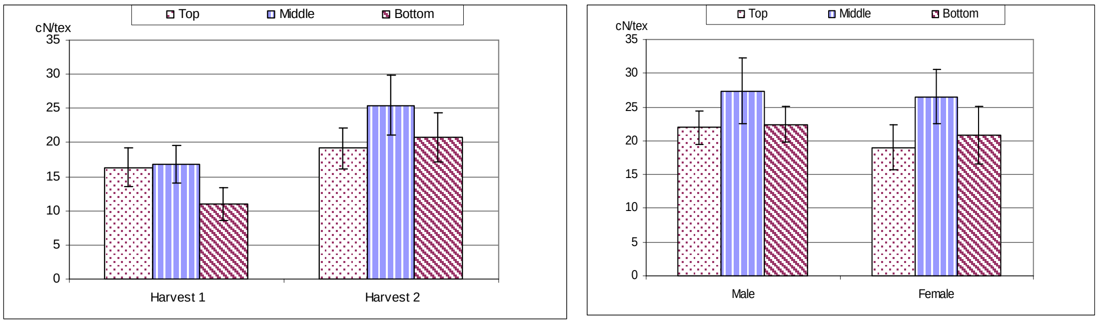


Figure 45 Hemp fiber collective strength measured with the Stelometer device, mean value for two harvest dates of male and female plants form harvest 2.

Fiber from fresh and dry decortications were highly significant different. Fiber strength from fresh decortication was 16.38, 16.83, 10.92 $cN.tex^{-1}$ from top, middle, bottom, respectively. While the result from dry decortication were 23.37, 27.29, 23.26 $cN.tex^{-1}$ from top, middle, bottom, respectively. Fiber strength of harvest 1 (16.4, 16.8, 10.9 $cN.tex^{-1}$; top, middle and bottom, respectively) was significant different from the strength of harvest 2 (19.2, 25.5, 20.8 $cN.tex^{-1}$; top, middle and bottom, respectively). From harvest 1, the top and middle parts of the stem had similar tensile strengths, while the bottom part was weaker. From harvest 2, the trend of strength in stems had changed: the middle part was strongest where as top and middle were almost equal. While male stems (22.0, 27.4, 22.4 $cN.tex^{-1}$; top, middle and bottom, respectively) were slightly stronger than female (19.0, 26.5, 20.8 $cN.tex^{-1}$; top, middle, bottom, respectively), the standard deviation bar showed the same range of strength within both sexes.

Consider the tenacity from other plant natural fiber by Stelometer, tensile strength of flax was 42-69 $cN.tex\text{-}^{1}$ (van de Velde and Baetens, 2001); hemp was 20-33 $cN.tex^{-1}$ (Fischer *et al*., 2005; Dreyer *et al*., 2002); nettle was 42 $cN.tex^{-1}$ (Dreyer *et al*., 2002) and cotton was 17-34.6 $cN.tex^{-1}$ (Lazo *et al*., 1994), 15-40 (Dreyer *et al*., 2002). Thai hemp performed a lower tenacity than temperate hemp.

5.3.2 Diastron method

Strength results of hemp fiber and fiber bundles measured in a collective test were unrivaled when the number of tested elements differs greatly. The influence of the number of elements in a collective test on the results had revealed as a new understanding of testing method (Suh *et al.*, 1994). The number of tested fibers has the influence on collective efficiency in which the greater number of collective, the lower efficiency of result would present. Thus the highest efficiency of fiber could determine from the single element testing (Fig. 48). While the Stelometer was a test on the parallel fiber which contained of single fiber, single fiber collective, fiber bundle and fiber bundle collective, Diastron used for testing on the fiber single element which could be single fiber or single fiber bundle (Fig. 46).

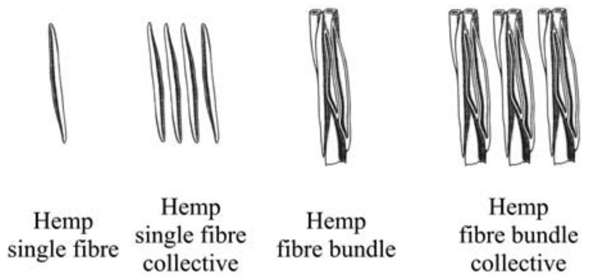


Figure 46 Possibilities to test hemp fiber (Adapted from Müssig, 2001)

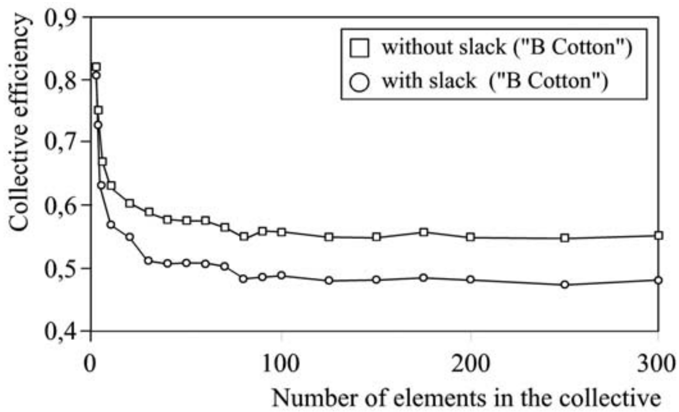


Figure 47 Influence of number of tested fibers in a collective on the collective efficiency (Adapted from Suh *et al.*1994)

Due to the limited of fiber amount of harvest 1, the fresh and dry decortication did not analyze the different tensile strength by Diastron. To compare the strength of the fibers and fiber bundles from stems from harvest 1, a single element was tested and the results showed more clearly difference between harvest 1 and 2 and between each part of stem (Fig. 48). Top and bottom parts of stems from harvest 2 clearly showed the higher strength than those from harvest 1. The homogenous of fiber single element strength was higher at harvest 2.

Tensile strength from Stelometer showed the highest fiber strength of male, middle part at 27.4 cN.tex^{-1} while its strength was 72.38 cN.tex^{-1} by Diastron. This effect was caused by the number of fiber tested which described above.

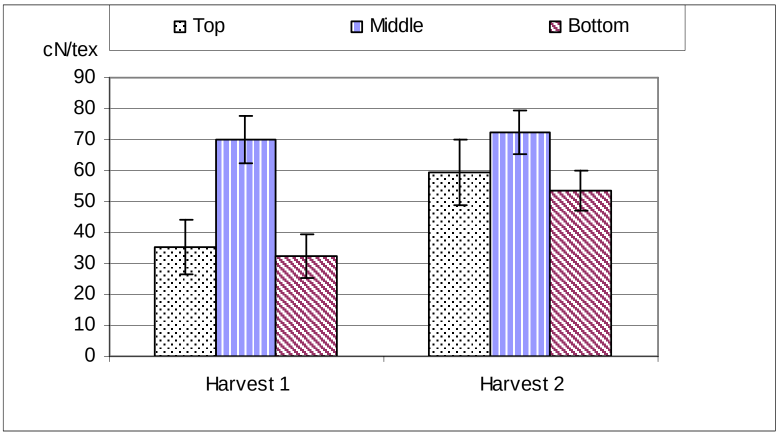


Figure 48 Hemp fiber single element strength measured with Diastron, mean values for two harvest dates.

The trend of strength on stem from Stelometer and Diastron were same. There was lower strength of top and bottom part at harvest 1 and it become more homogenous at harvest 2. Thus, at early stages of reproduction growth, the maturity of fiber was performing in whole stem. The trend of tensile strength by Diastron that test individual fiber element was clearer than those tested by Stelometer but more time consuming and higher cost. Thus the testing method on Diastron should carry on the sample that needed a specific comparison.

5.4 Fiber bundle length

Fiber and fiber-bundle length was measured by an Almeter after hemp samples were chemically and mechanically separated with the coarse separator. Average length varied from 22.0 to 28.4 mm. At harvest 1 fiber lengths were 28.3, 24.2, 23.7 and at harvest 2 they were 22.3, 27.2, 27.3 mm, respectively. At harvest 2 male plant fiber lengths were 22.0, 28.0, 28.4 mm, and female fiber length were 22.6, 26.3 and 26.1 mm.

Hemp fiber was classified in short fiber, which length shorter than 44 mm long according to textile classification. In textile spinning process, for example cotton, fiber under 5 mm long was lost during processing by flying as dust, while fiber under 15 mm almost only contribute to yarn filling but not to yarn strength. Only fibers over 15 mm contribute to yarn strength and other yarn characteristics. Thus fiber length distribution was useful information to evaluate the fiber characteristics in real application include the spinning equipment that can apply to fiber.

The result of the Almeter testing was a frequency of fiber distribution (Fig. 49). Testing method was evaluated frequency of fiber bundle length of the parallel fiber sample with measure specific at 2.5 mm band. Mean length was varied from 22.0 to 30.2 mm. Fiber bundle shorter than 25 mm (L(Q) < 25 mm) was 48.7 to 71.3 %, this means the fiber that can use in spinning process was 50 % or less. Fiber distribution at 50 % (L(Q) 50%) was 18.1 to 24.4 mm. Fiber distribution at 1 % (L(Q) 1%) presented the longest fiber length that can found in the sample was 61.8 to 80.6 mm. The median value and short fiber content was presented in (Table 10).

The Almeter measurements of the chemically separated samples showed length values allowing the tested hemp to be used for spinning on modern cotton spinning equipment. Further tests need to be carried out to evaluate the quality of the produced hemp in real spinning trials e.g. with an open-end cotton spinning technique.

Table 10 Fiber length values from Almeter measurements of chemically and mechanically separated hemp fiber for decortication method, two harvest dates and male and female plants.

Sample	Part	Mean	CV %	L (Q) < 25 mm	L(Q) 50%	L(Q) 1%
Fresh decortication	Top	28.3	53.8	51.5	24.4	76.9
	Middle	24.2	52.0	64.1	20.7	66.8
	Bottom	23.7	58.6	66.2	18.5	68.3
Dry decortication	Top	29.6	55.4	51.8	24.2	84.0
	Middle	25.4	52.7	61.5	21.7	74.5
	Bottom	30.2	62.8	48.7	25.4	94.3
Harvest 1	Top	28.3	53.8	51.5	24.4	76.9
	Middle	24.2	52.0	64.1	20.7	66.8
	Bottom	23.7	58.6	66.2	18.5	68.3
Harvest 2	Top	22.3	54.8	70.6	18.1	63.8
	Middle	27.1	56.1	58.1	22.3	76.9
	Bottom	27.3	57.2	57.1	22.0	76.5
Male	Top	22.0	54.5	69.8	17.5	61.8
	Middle	28.0	55.8	55.7	22.7	80.6
	Bottom	28.4	57.2	54.2	23.1	78.9
Female	Top	22.6	55.0	71.3	18.7	65.8
	Middle	26.3	56.3	60.5	21.8	73.3
	Bottom	26.1	57.3	60.0	21.0	74.0

L(Q)<25mm = % fiber shorter than 25mm

L(Q) 50% = median

L(Q) 1% = 1% fiber shorter than this value

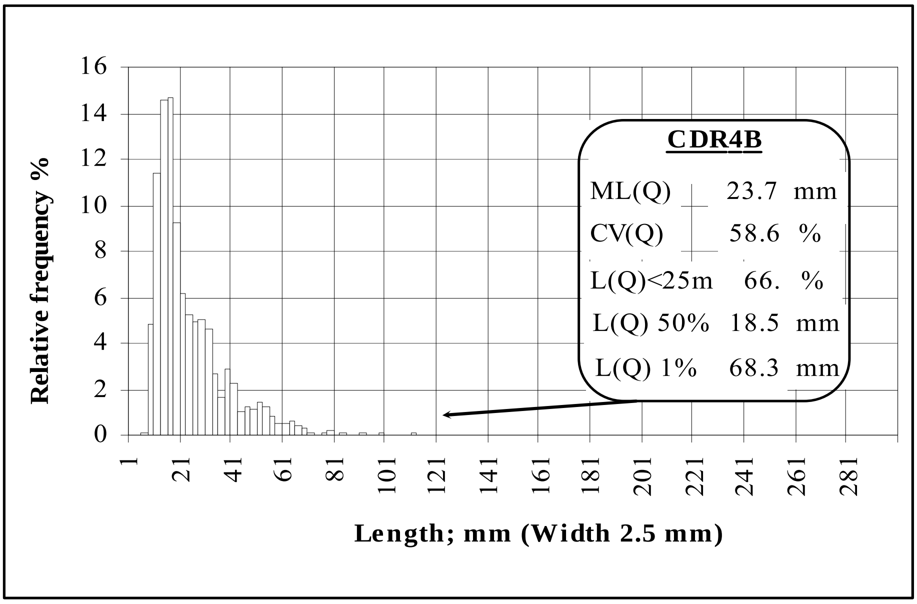


Figure 49 Chart resulted from Almeter show the relative frequency of fiber length at 2.5 mm width.

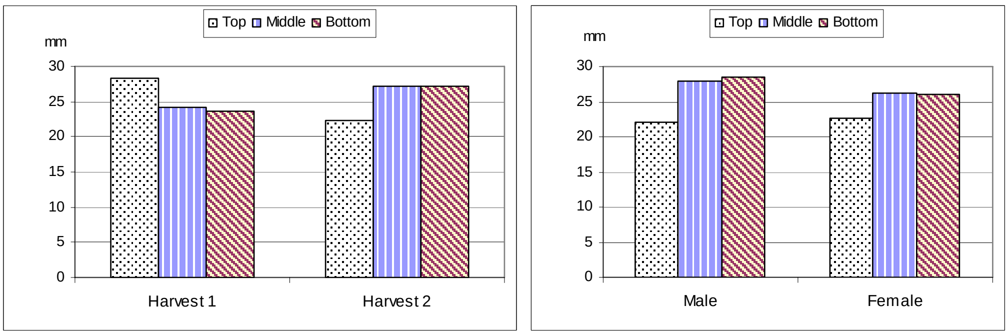


Figure 50 Fiber length among harvest 1, 2, male and female plant, measured with Almeter.

5.5 Lignin content in fiber

The lignin content estimated from Kappa number is given in Fig. 51. Lignin was dominant in the bottom part in every treatment. From harvest 1, lignin contents as Kappa numbers were 11.9, 12.5, 16.6 and for harvest 2 they were 10.7, 13.0, 17.3, for top, middle, bottom, respectively. There was no difference in lignin content for the two harvest times. Toonen *et al*. (2004) reported that the level of lignin, as indicated by the percentage of acid detergent lignin (ADL), did not increase during plant development.

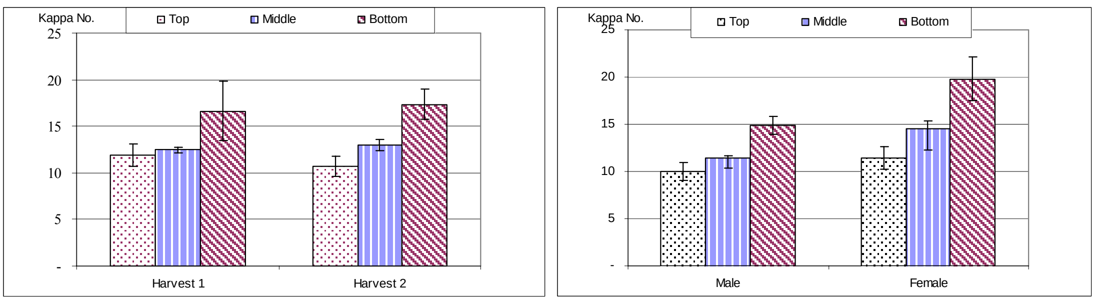


Figure 51 Lignin content estimated by Kappa number - mean value and standard deviation as error bar

Lignin contents were 10.0, 11.4, 14.9 in male plants and 11.4, 14.5, 20.0 in female plant, for top, middle, bottom, respectively. The difference in lignin content between the bottom and top of plant was highly significant. The distribution of lignin on hemp stem from the bottom and declined at the top has reported by Hernàndez *et al*. (2006).

From the physical properties of hemp, this study showed slightly different quality between male and female plants. In this research fiber from male plants had lower lignin content than female plants. Less lignin content allow less delignification and less chemical agent for bleaching process. Each application had its own demand on fiber characteristics and processing of the fiber (Toonen *et al*, 2004).

5.6 Cross sectional view by SEM

Fiber from harvest 1 had a wall thickness 4.08 µm which less than 4.67 µm from harvest 2, and cell diameter of fiber from harvest 1 was 18.28 µm which smaller than 20.13 µm from harvest 2 (Table 11). Thus, the fiber fineness value of harvest 1 was lower than harvest 2 (Fig.41). Consequencely, Thai hemp was 13 to 27 µm which finer or than temperate hemp variety Futura 75, which the primary fiber cells ranged from 17 to 41 µm (Amaducci *et al*., 2005). Cross sectional view demonstrated wall maturity. In Fig. 52A, middle, wall filtration makes a small lumen and fiber had round shape. These characters made fiber strong, thus the fiber strength measured by Diastron is high. Fiber maturity in hemp studied by Amaducci *et al*. (2005) had reported that the maturity appeared to have already reached its maximum at full flowering. The maturation of fibers progressed from the outer to the inner part of the stem. At full and late flowering the maturation degree was similar along the stem.

Dislocations are local misalignments of cellulose microfibrils in cell wall of natural fiber such as wood, flax and hemp. Dislocations are areas where the direction of the microfibril (the microfibril angle) differs from the microfibril angle of the surrounding cell wall. For most uses, dislocations have a negative influence on the performance of fiber-based products (Thygesen and Hoffmeyer, 2005; Thygeson *et al*., 2006). In harvest 2, fiber from bottom part was 22.75 µm which larger than 17.88 µm of middle part and wall thickness of bottom part was 6.25 µm which thicker than 4.25 µm of the middle. The cell diameter and wall thickness in harvest 2, bottom part should stronger than middle part. But the single element strength by Diastron (Fig. 52) of the middle part was higher than the bottom, this might because of the effect of allocation on fiber surface (Fig. 53B, bottom).

Table 11 Wall thickness and cell size of fiber hemp from harvest 1 and 2

	Part	Wall thickness (μm)	Dimension 1 (μm)	Dimension 2 (μm)	Avg. Diameter (μm)
Harvest 1	Top	3.25	33.60	8.00	20.80
	Middle	4.75	17.75	11.00	14.38
	Bottom	4.25	29.00	10.30	19.65
	Avg	4.08	26.78	9.77	18.28
Harvest 2	Top	3.50	24.50	15.00	19.75
	Middle	4.25	28.75	7.00	17.88
	Bottom	6.25	28.00	17.50	22.75
	Avg	4.67	27.08	13.17	20.13

The statistical analysis of fiber fineness from Airflow and OFDA did not different among testing method. The fiber fineness of H1 and H2 did not different but fiber from difference part of same treatment was highly significant difference. Fiber strength resulted from Stelometer differed among H1 and H2 while the result from Diastron was highly significant difference. Lignin content was not significant difference among H1 and H2. The difference of fiber fineness, fiber strength and lignin content were highly significant difference between the fibers from each part on stem. The fiber properties of sample from difference decortication method performed in fiber strength but not fiber fineness while the difference sex had an impact on fiber strength but not fiber fineness (Table 12).

Fiber properties of Thai hemp and others fiber was the same range. Fiber fineness from OFDA of nettle (17 μm) and flax (15.3 μm) were close to the fineness of Thai hemp (14.08-18.86 μm) from the same testing method. Fiber collective strength of nettle (13-23.5 $cN.tex^{-1}$) was close to Thai hemp (10.9-27.4 $cN.tex^{-1}$) (Dreyer *et al*., 2002). Information on chemical and physical properties are scattered in the scientific literature. In many cases, different analytical procedures have been used to collect the data so it is difficult to compare one set of data with any other set (Rowell *et al*., 2000). Thus the comparison of Thai hemp fiber properties with others fiber was limited.

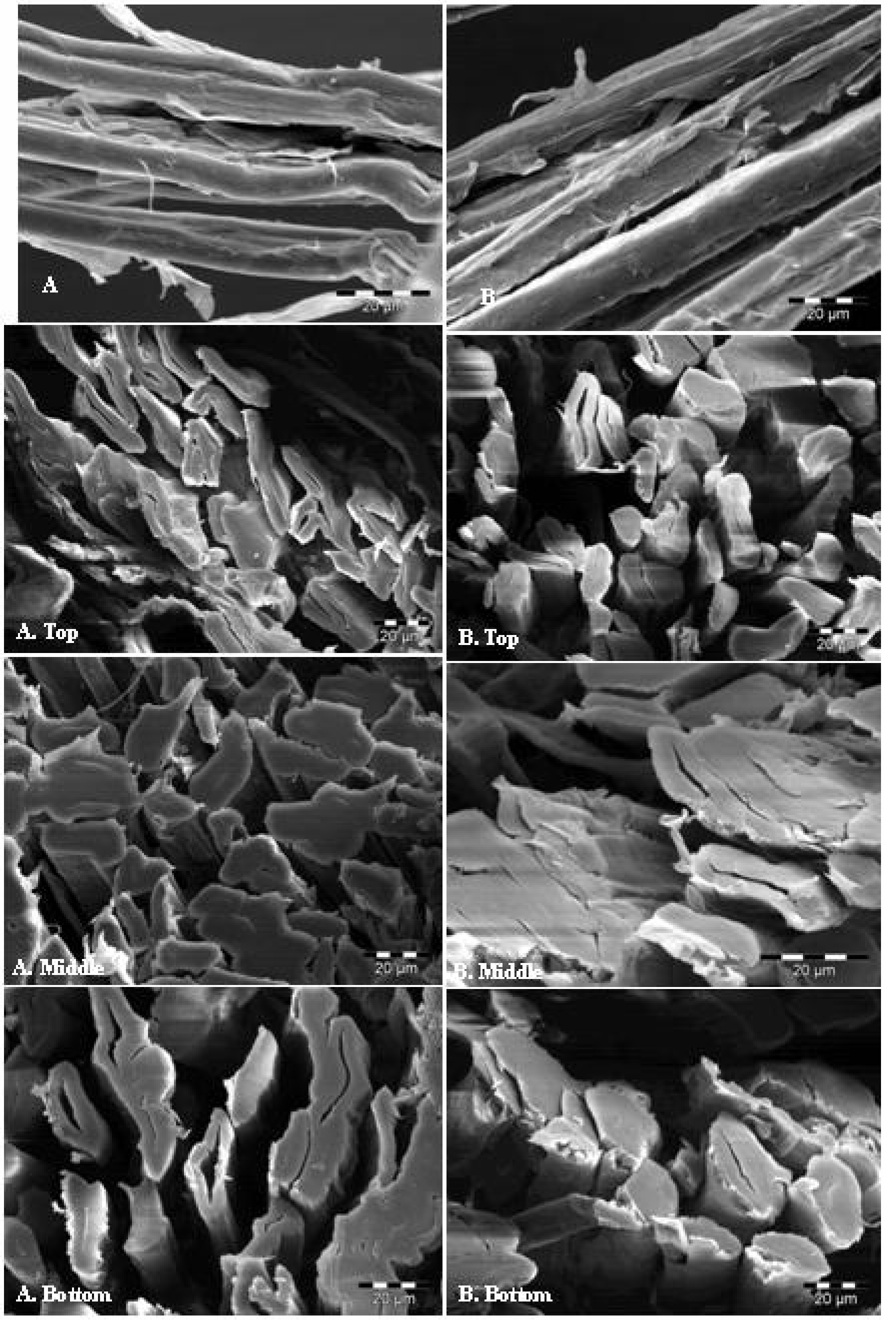


Figure 52 Photomicrograph of hemp fiber from harvest 1 (left) and 2 (right).
A fiber from hemp harvest 1
B fiber from hemp harvest 2

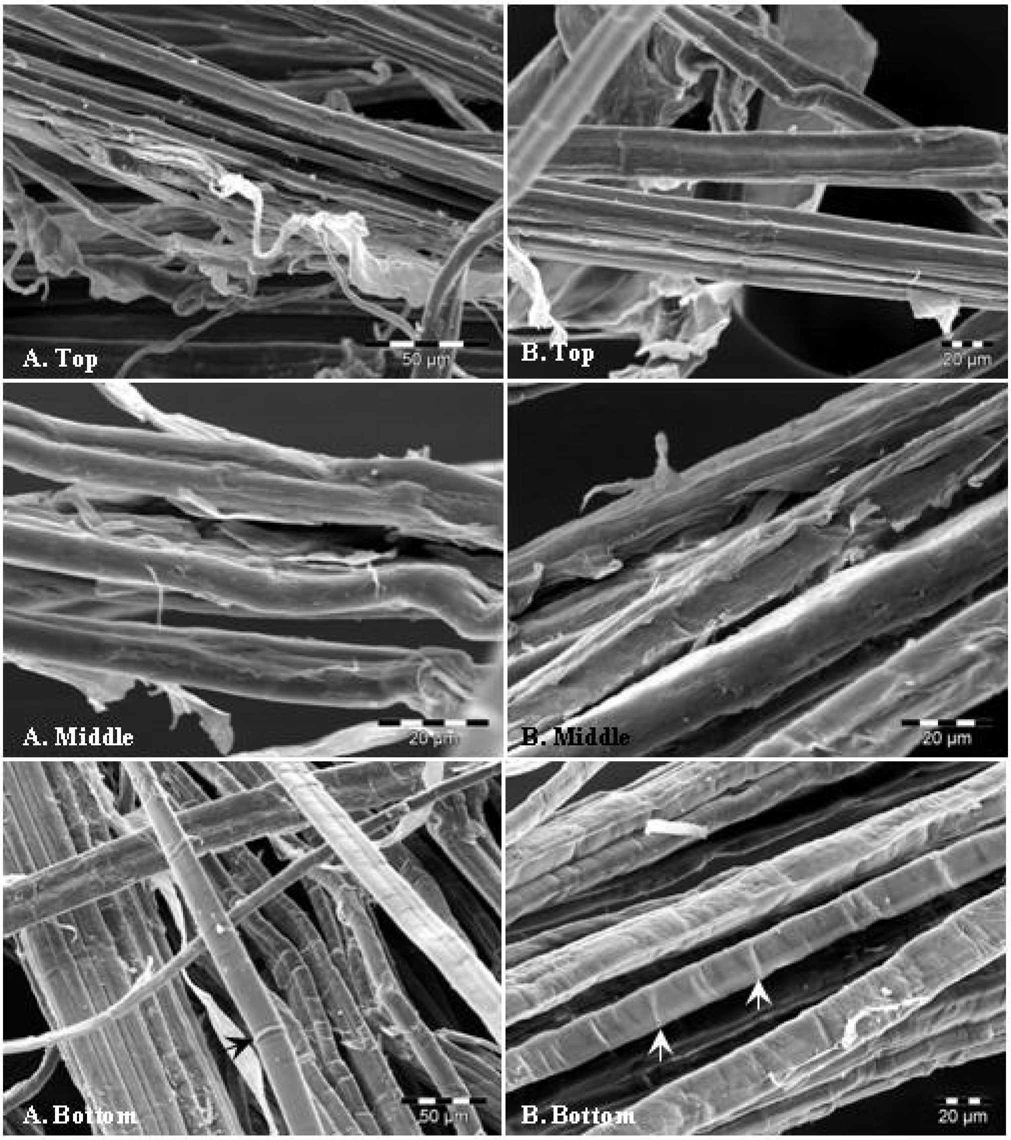


Figure 53 Photomicrograph of hemp fiber from top, middle and bottom part of stem. Arrow point to allocation on fiber surface.
A. fiber from hemp harvest 1
B. fiber from hemp harvest 2

Table 12 Mean comparison of fiber properties of Thai hemp.

Measurement	Part	Harvest 1		Harvest 2	
		Fresh	**Dry**	**Male**	**Female**
Airflow 200	Top	14.23 a	14.75 a	18.28 a	17.04 a
	Middle	17.55 b	16.24 b	23.68 b	24.43 b
	Bottom	23.16 c	21.97 c	26.08 c	27.08 c
	CV (%)	8.2		9.5	
	Mean	18.32	17.65	22.68	22.85
F-test	Part	**	**	**	**
	Mean	17.98		22.77	
	Treatment/ Sex	ns		ns	
	Harvesting time	**			
OFDA	Top	14.08 a	14.88 a	14.90 a	15.26 a
	Middle	15.72 b	15.68 b	18.18 b	18.86 b
	Bottom	17.48 c	16.90 c	18.36 b	19.10 b
	CV (%)	5.5		5.5	
	Mean	15.76	15.82	17.15	17.74
F-test	Part	**	**	**	**
	Mean	15.79		17.44	
	Treatment/ Sex	ns		ns	
	Harvesting time	**			
Stelometer	Top	16.38	23.37	21.96 a	16.63 a
	Middle	16.82	27.28	27.37 b	21.43 b
	Bottom	10.92	23.26	22.39 b	19.14 b
	CV (%)	18.7		16.3	
	Mean	14.71	24.64	23.90	19.06
F-test	Part	**	**	**	**
	Mean	19.67		21.48	
	Treatment/ Sex	**		**	
	Harvesting time	*			
Diastron	Top	35.36 a		59.38 a	
	Middle	69.79 b		72.38 b	
	Bottom	32.45 a		53.62 a	
	CV (%)	33.4			
	Mean	45.87		61.79	
F-test	Part	**		**	
	Harvesting time	**			
Lignin	Top	11.85 a		9.97 a	11.43 a
	Middle	12.45 a		11.40 a	14.53 b
	Bottom	16.62 b		14.90 b	19.78 c
	CV (%)	14.8		9.6	
	Mean	13.64		12.09	15.25
F-test	Part	**		**	**
	Mean Sex	13.64 -		13.67 **	
	Harvesting time	ns			

ns = non significant difference
* = significant difference
** = highly significant difference

6. Fiber Yield

The stem growth and fiber yield from 5. Fiber properties was described in this part. Hemp was planted on July 10th 2004 and harvest at 65 days (harvest 1) at vegetative stage and sex was invisible. At 120 days (harvest 2) flowering time, male and female plants were separated (Fig. 54). At harvest 1 hemp stem was from density 24 plants.m^{-2} with height 165.98 cm and D_{10} 8.24 mm. At harvest 2 hemp stem was from density 23.6 plants.m^{-2} with height 267.35 cm and D_{10} 11.15 mm. The difference height among harvest 1 and 2 was 101.30 cm and different D_{10} was 2.91 mm. All treatment decortication was on fresh stem except the treatment on dry decortication in harvest 1.

At harvest 1, decortication method had divided into fresh and dry decortication. Fiber from fresh decortication was from density 27 plant.m^{-2} with 166.21 cm height and D_{10} 8.10 mm, from dry decortication was from density 21 plant.m^{-2} with 165.75 cm height and D_{10} 8.39 mm. Fiber yield by the percentage of fiber weight was 12.84% from fresh decortication and 12.13% from dry decortication.

All decortication of hemp in industrial and research was carried on dry stem. Dry decortication is said to be quicker and not to be restricted to the harvesting season, whereas fresh decortication generally yields fiber for better quality by reduced the secondary bast fiber in peeled bast (Jarman *et al*., 1978). Thai hemp was less secondary bast fiber (Fig.18) when compare to temperate hemp (Fig. 19). Thus, decortication method was less impact to fiber quality on Thai hemp. Conversely, fungi infection which is the importance factor to fiber damage in tropic was an importance criterion. Thus, fresh decortication was recommended for Thai hemp.

Fiber yield in harvest 1 was 12.84 % while in harvest 2 was 9.87%. The reducing percentage of yield was due to the partition of weight to the woody part which increases from 75.29% at harvest 1 to 78.31% at harvest 2. Conversely, fiber weight was increased from 25.82 at harvest 1 to 44.47 g.m^{-2} at harvest 2.

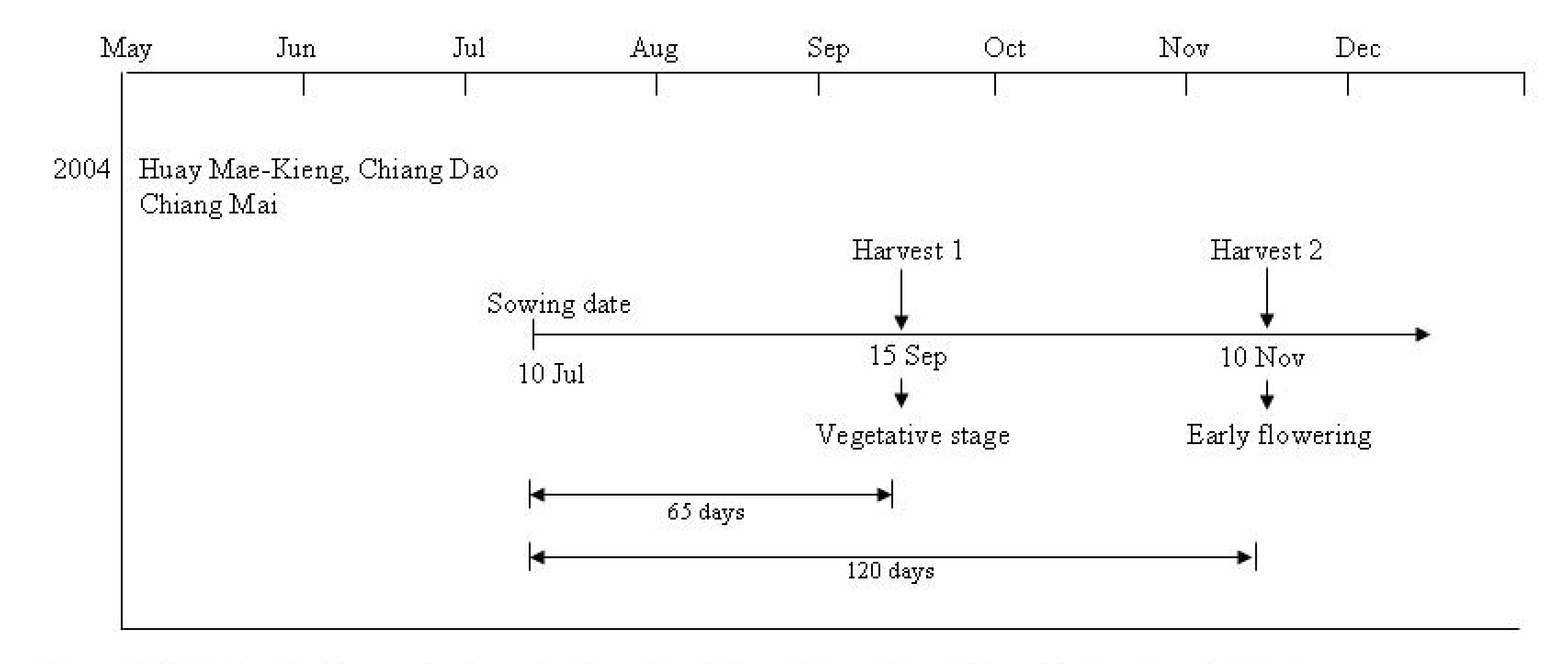


Figure 54 The detail of harvesting hemp in Huay Mae-Kieng, Chiang Dao, Chiang Mai province in 2004

Table 13 Average stem yield distribution by weight and by percentage

Treatments	Density	Height (cm)	D10 (mm)	Part	Yield by weight ($g.m^{-2}$)			Yield by percentage (%)		
					Wood	Bast	Fiber	Wood	Bast	Fiber*
Fresh decortication				Top	22.82	7.42	2.84	75.47	24.53	9.39
	27	166.21	8.10	Middle	53.98	17.27	8.75	75.76	24.24	12.28
	± 6.16	± 16.34	± 0.78	Bottom	92.92	31.04	15.35	74.96	25.04	12.38
					169.72	**55.73**	**26.94**	**75.29**	**24.71**	**12.84**
Dry decortication				Top	24.34	7.82	3.34	75.70	24.30	10.39
	21	165.75	8.39	Middle	47.21	15.47	7.88	75.32	24.68	12.57
	± 4.12	± 15.23	± 0.70	Bottom	86.24	26.34	13.48	76.60	23.40	11.97
					157.79	**49.63**	**24.70**	**76.02**	**23.98**	**12.13**
Harvest 1				Top	23.58	7.62	3.09	75.58	24.42	9.89
	24	165.98	8.24	Middle	50.59	16.37	8.32	75.54	24.46	12.43
	± 5.87	± 14.90	± 0.71	Bottom	89.58	28.69	14.42	75.78	24.22	12.18
					163.76	**52.68**	**25.82**	**75.29**	**24.71**	**12.84**
Harvest 2				Top	31.57	9.78	3.94	76.28	23.72	9.61
	23.6	267.35	11.15	Middle	99.23	30.40	13.76	76.54	23.46	10.62
	± 2.41	± 7.25	± 0.92	Bottom	176.91	44.91	20.68	79.60	20.40	9.38
					309.77	**94.27**	**44.47**	**78.31**	**21.69**	**9.87**
Male				Top	27.26	8.77	3.66	75.66	24.34	10.15
	14	274.35	10.29	Middle	96.64	31.49	14.07	75.42	24.58	10.98
	± 4.28	± 11.68	± 1.14	Bottom	199.50	46.72	21.74	81.03	18.97	8.83
					327.51	**105.36**	**51.64**	**77.37**	**22.63**	**9.62**
Female				Top	35.89	10.78	4.23	76.90	23.10	9.06
	10	260.35	12.02	Middle	101.82	29.31	13.44	77.65	22.35	10.25
	± 4.36	± 14.23	± 1.60	Bottom	154.32	43.10	19.62	78.17	21.83	9.94
					292.02	**83.19**	**37.30**	**77.57**	**22.43**	**9.94**

* Percentage of fiber calculated from fiber weight . stem weight^{-1} . 100

The density of harvest 1 and 2 were 24 and 23.6 plant.m^{-2}, respectively. Thus the difference yield should not direct from the effected of plant density but stage of plant growth. At harvest 2, male and female was separated. Male stem was 274.35 cm in height and 10.29 mm in D10 while female was 260.35 cm in height and 12.02 mm in D10. Male stem was higher and more slender than female which is the characters in hemp plant (Lisson and Mendhem, 2000).

Fiber yield distribution on stem was mainly on the middle section (12.43 % in harvest 1 and 10.62 % in harvest 2) (Table.13). At harvest 2 as a maturation stage, weight partitioning were 78.31 % wood and 21.69 % bast. In bast portion only 47.17 % of bast weight or 9.87 % of stem weight was fiber. This means if reduce wood and increase bast, it possibility that the percentage of fiber would increase. Compare to temperate hemp variety Futura 77 yield bark proportions upto 40 % at density 110 plant.m^{-2} (Lisson and Mendham, 2000), variety Kompolti hybrid TC yield bark proportion 33.8 % at density 30 plant.m^{-2} with plant height 352 cm. The reported by van der Werf *et al*. (1995) in Landraces from Korea and Japan were found to give much higher stem yields than Kompolti and Kompolti Hybrid TC, but had very poor bark percentages. When Thai hemp yield a lower bast content as in Korea and Japan hemp, thus each hemp varieties performed the specific characters among yield, quality and the response to the environment.

For weight partition to wood and bast in harvest 1 found the weight mainly located at woody part of the bottom. There were 41.22 % in harvest 1 and 44.87 % in harvest 2 and located at middle 23.94 % in harvest 1 and 25.34 % at harvest 2. Top part was a wood 10.12 % and 8.10 % at harvest 1 and 2, respectively. The yield distribution of Thai hemp was same trend as the reported by Mediavilla *et al* (2001), an approximate 54 % of the fibers were located in the bottom part, 34 % in the middle and only 12 % in the top part. Thus this yield distribution on hemp stem might be the generally phenomenon of fiber in this species.

The component of bast was mainly the fiber cell and substance termed gum, which rules as adhesive each elementary fiber. After chemical retting, approximately

50 % of bast was divided into fiber and gum (Fig. 55-58). The main constituents of the gum were pectins, hemicelluloses and lignin which was main constitutes of middle lamella and the non-cellulosic compounds of the primary and secondary cell wall (Keller *et al*., 2001). That is dissolved during degumming or retting process.

It is common knowledge that a high bast yield and bast fiber content were advantageous for the production of textiles (Mediavilla *et al*., 2001) and the cultivation in many countries was high plant density (van der Werf *et al*., 1994; Cromack, 1998; Struik *et al*., 2000). The reason for growing hemp at high density was to allow plant slenderness otherwise the stem will become too thick and this would increase wood portion. When diameter of hemp stem relate to the wood and secondary bast fiber formation, these conditions would increase fiber quality (Hernàndez *et al*., 2006) and increase bast fiber content (van der Werf *et al*., 1995) which associated with the final stem length (de Meijer and Keizer, 1994). These affected was found not only in hemp but also in others bast fiber crops as kenaf. Up to 90 % of the variance in stem yield could be accounted for by plant density and mean stem length (Muchow, 1979). The relationship between yield and maximum plant density in fiber hemp is therefore approximated by its self-thinning line (van der Werf *et al*., 1995). The ability to manipulate core and bark fiber yields could be an important crop management tool when growing fiber for core and bast fiber-specific products (Cook and Scott, 1998).

Although the cultivation have a great impact on fiber quality and yield but genetic differences had a greater impact on stem bast fiber content than stem density (Cromack, 1998). Thai hemp perform a good quality of fiber for textile when compare to others hemp and it possible to improve the fiber properties and yield by increasing plant density and planting hemp at early time of year. The question of how density would be, this depends on the product and utilization of Thai hemp and the purpose of the production, each product need specific properties of fiber. For textile purpose need the hemp raw material that can go into the spinning and weaving process which dependent on the specific needed of each spinning machine and technique. The optimized yield and fiber quality for specific purpose would bring the successful both production and utilization of Thai hemp.

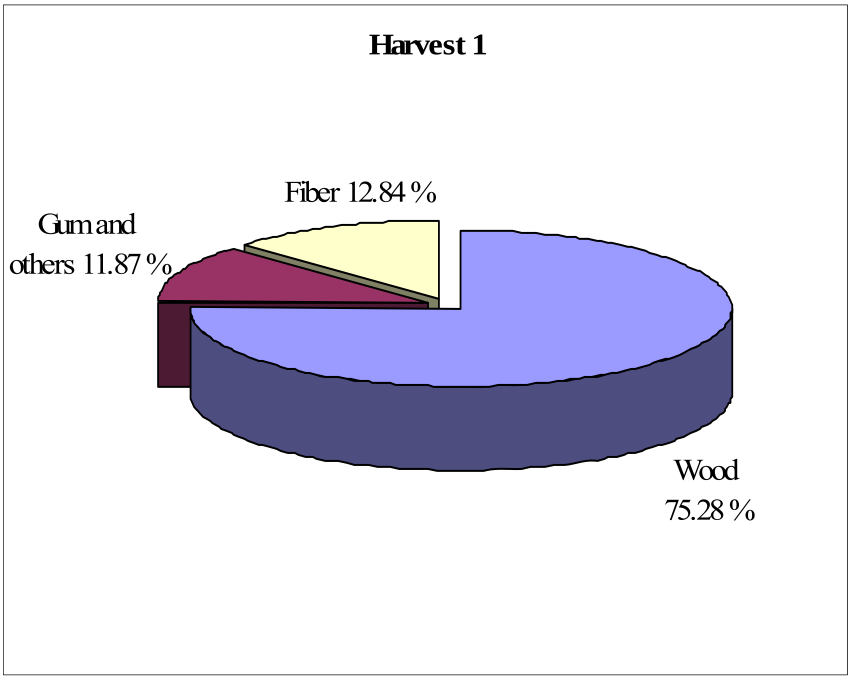


Figure 55 Diagram of yield distribution on stem at harvest 1

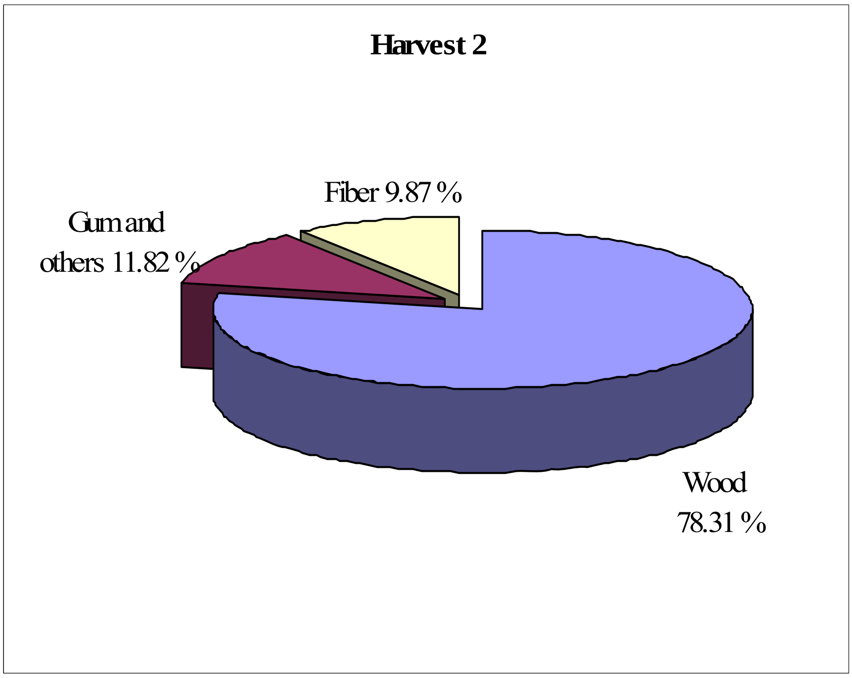


Figure 56 Diagram of yield distribution on stem at harvest 2

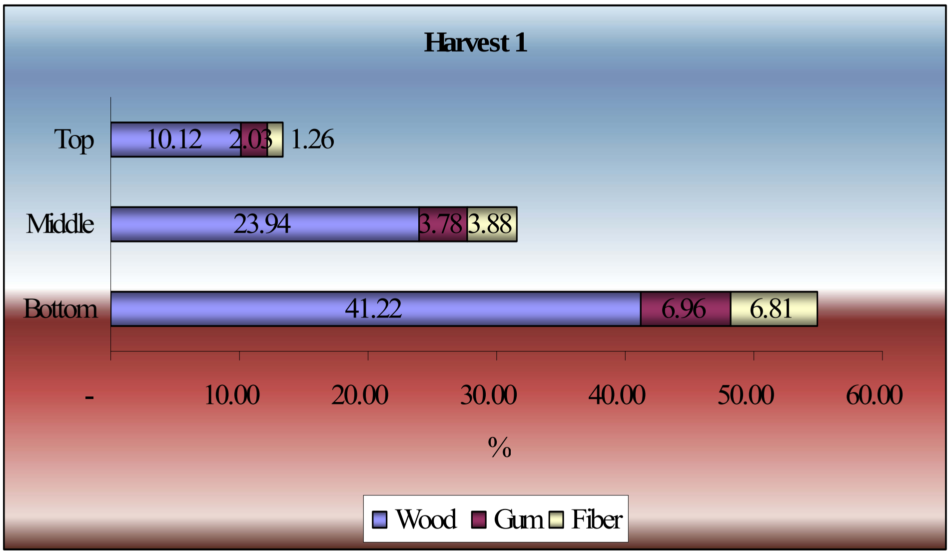


Figure 57 The percentage of weight distribution on harvest 1 hemp stem

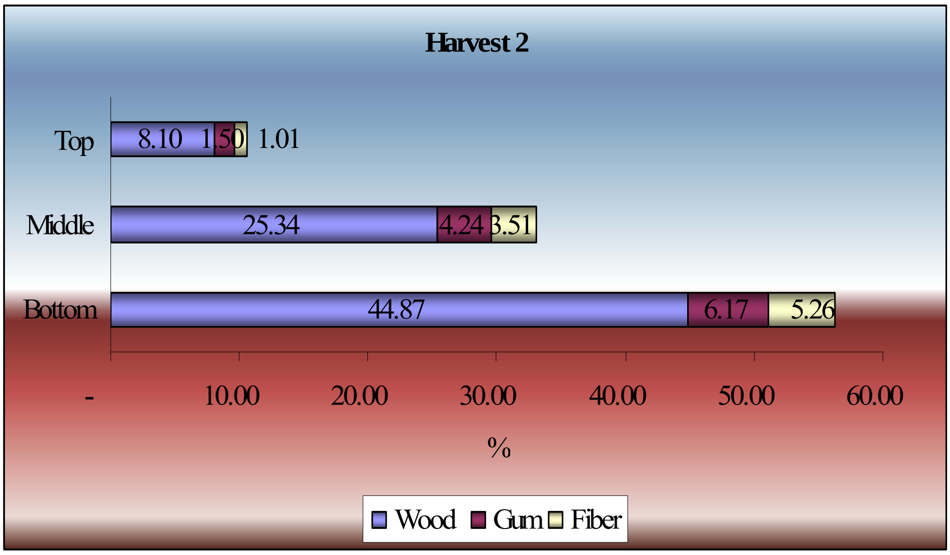


Figure 58 The percentage of weight distribution on harvest 2 hemp stem

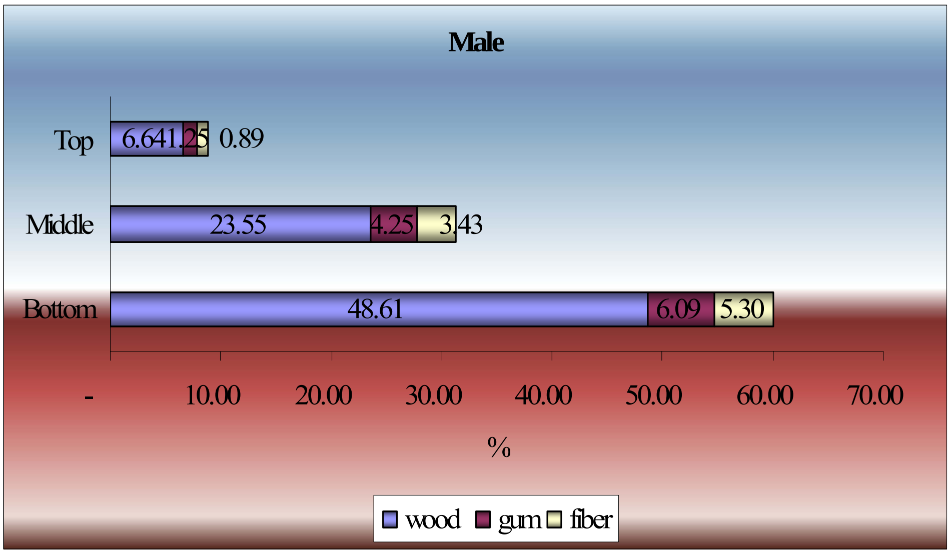


Figure 59 The percentage of weight distribution on male hemp stem

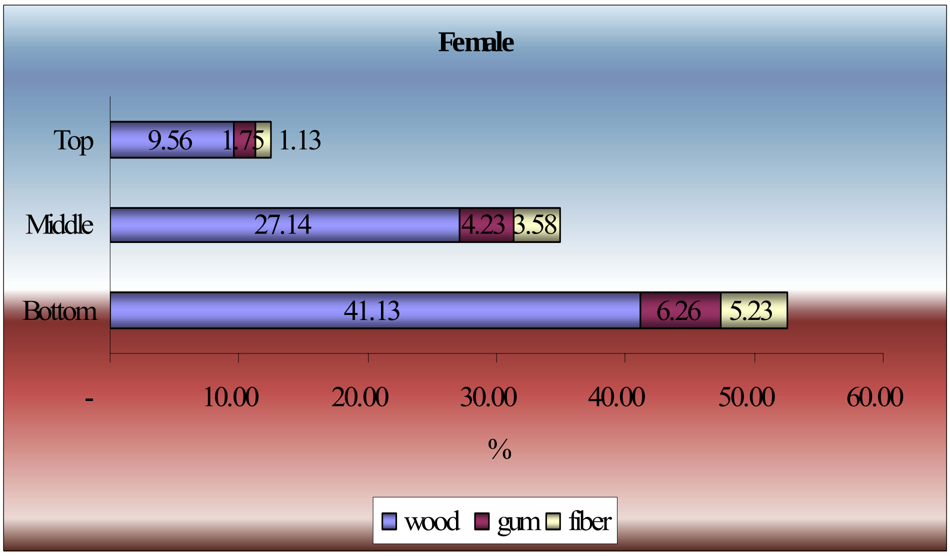


Figure 60 The percentage of weight distribution on female hemp stem

CONCLUSION AND RECOMMENDATION

Conclusion

1. Thai hemp is dioecious, leaves opposite decussate and changed to spiral upward. Male inflorescence is panicle with 5 tepals, 5 stamens which loculicidal septate. Female inflorescence arranged in spike. Each floret cover with bract which located glandular trichome. Seed is achene in ovoid shape. Thai hemp flowering in 2002 for 2 sowing date performed a stage of seed set at the same time on 15th December. Stem height of S1 was 135.5 cm and 104 cm, S2 was 56 and 30 cm in male and female respectively. S1 D_{10} was 9 and 8 mm in male and female, respectively. S2 was 5 mm in D_{10}.

2. Anatomical structure of hemp root is diarch at primary growth, secondary growth is same as ordinary dicotyledons. Leaf covered with non glandular and glandular trichome. Crytolith hair on the upper epidermis contains calcium carbonate while glandular trichome on the lower epidermis contains a resin drug. Primary growth of stem was an eustele as ordinary dicotyledons and secondary growth of stem found primary phloem fiber or primary bast fiber with the cellulose wall. Secondary bast fiber was smaller with 34 mm length and 16 µm diameter. Wood fiber was 22.74 µm and 17.71 µm length, 0.678 mm and 0.558 mm diameter in male and female plants, respectively.

3. Thai hemp is short day plant with the critical day length among 11-12 hrs. The early sowing date in May 2003 can reach height to 419.23 cm with D_{10} 17.03 mm and male plant exceeded female at final stem length. The ratio of male : female plant in the population was 57.68 : 42.32. The late sowing date would effected to hemp growth by reduce rate of maximum stem length, diameter and consume less time to stop their growth and the changing from vegetative to reproductive phase was faster. The phyllotaxis changed from opposite decussate to spiral occurs at leaves pair 5.86 to 6.33. The rate of leaves appearance was increased dramatically when rate of stem elongation decrease. This effect was influence of changing growth pattern to

reproductive organ. The period of floral initiation to seed ripening take 3 months at S1 and the longevity of this period will decrease at late planting.

4. The climate that had the most impact on plant growth and development was the daylength which control the flowering of hemp. Daylength approximately 11-12 hrs was the critical day length for photoperiodism. Rainfall and temperature were less impact to plant development but to plant growth. Exceed rainfall may reduce growth of hemp. Generally plant and site was an interaction effect but this is not include in this experiment.

5. The average fiber fineness measured by the Airflow method varies between 17.65 to 22.9 $FBAI_{200}$. The fiber fineness from OFDA method varies from 14.9 to 19.10 µm. Tensile strength measure by Stelometer varies from 10.9 to 25.5 $cN.tex^{-1}$. The strength by Diastron varies from 27.4 to 72.38 $cN.tex^{-1}$. Fiber bundle length varies from 22.3 to 28.3 mm. Lignin content was not difference among harvesting time. The Kappa number varies from 10.7 to 17.3. The difference of fiber fineness, fiber strength and lignin content were highly significant difference between the fibers from each part on stem. The fiber properties of sample from difference decortication method performed in fiber strength but not fiber fineness while the difference sex had an impact on fiber strength but not fiber fineness. Harvesting time of hemp should carry on flowering time in which the fiber maturity was reach into the maximum stage.

6. Thai hemp which grown at the density between 20 to 30 $plant.m^{-2}$ can yield fiber at 9.87 to 12.84 % and bast 21.69 %. The wood portion was approximately 10, 25, 44 and bast was 2, 7, 12 % from top, middle, bottom, respectively. The yield distribution on stem was mainly on the bottom portion. Fiber yield and quality was the influence from the genetic controlled, cultivation method, growth stage of plant, testing method, and the position of fiber on stem.

Recommendation

1. Fiber properties of Thai hemp performed a good quality. Further tests need to be carried out to evaluate the quality of the produced hemp in real spinning trials.

2. The possibility to improve the quality and yield of hemp is planting at high density. The optimized yield and fiber quality for specific purpose would bring the successful both production and utilization of Thai hemp.

3. The woody core is useless part for hemp fiber in textile industrial but it can make a light weight particle board or can mixed with others fiber for paper making. Thus the utilization of all part of hemp for non-waste products should investigate in the future.

4. Due to hemp cultivation is prohibited in Thailand which often conflict to Hmong people who grow hemp for their cloth and sell their hand made products, thus to find out the solution should consider for the benefit of the country both for drug control and the conservation of Ethnobotany by Hmong people.

5. Hemp cultivation in many countries were associated with breeding program both new cultivar for low THC content and high fiber yield and quality. Thus the breeding program is needed to investigate along with the research in this species.

6. The utilization of hemp fiber in industrial should concern with the crop management and the country law.

7. The retting method for bast fiber usually produces waste water in the process thus the enzymatic retting should be an option for environmental concern.

8. Cannabinoid content in Thai hemp is needed to test both THC and CBD. Which are criteria for international hemp cultivation law and useful for both breeding program and drug control.

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APPENDIX

Appendix Figure 1 Shapes of fiber ends (Modified from Catling and Grayson, 1982).

แบบ ย.ส. 22

ใบอนุญาต

ผลิต ~~จำหน่าย นำเข้า ส่งออก หรือ มีไว้ในครอบครอง~~

ซึ่งยาเสพติดให้โทษใน ~~ประเภท 4 หรือ~~ ประเภท 5

ใบอนุญาตที่ ....3/2547..........

ใบอนุญาตฉบับนี้ให้ไว้แก่

.................................องค์การสวนพฤกษศาสตร์.................................

โดยมี ....นาย วีระชัย ณ นคร....................เป็นผู้ดำเนินกิจการ เพื่อแสดงว่า เป็นผู้รับอนุญาต ผลิต ~~จำหน่าย นำเข้า~~ ~~ส่งออก หรือ มีไว้ในครอบครอง~~ ซึ่งยาเสพติดให้โทษใน ~~ประเภท 4 หรือ~~ ประเภท 5

โดยมีสถานที่ ผลิต ~~จำหน่าย นำเข้า~~ ~~ส่งออก หรือ มีไว้ในครอบครอง~~ ชื่อ ....สวนพฤกษศาสตร์สมเด็จพระนางเจ้าสิริกิติ์....................

อยู่เลขที่ ....100.......... ตรอก/ซอย ....-..........

ถนน ....-.......... หมู่ที่ ....9.......... ตำบล/แขวง ....แม่แรม..........

อำเภอ/เขต ....แม่ริม.......... จังหวัด ....เชียงใหม่ 50180..........

โทรศัพท์ ......0 5329 8171-5..........

ใบอนุญาตฉบับนี้ให้ใช้ได้จนถึงวันที่ 31 ธันวาคม พ.ศ. ....2547.....และให้ใช้ได้เฉพาะสถานที่ซึ่งระบุไว้ในใบอนุญาตเท่านั้น

ให้ไว้ ณ วันที่ ....16....... เดือน ....พฤศจิกายน.......... พ.ศ. ....2547..........

....

([illegible])

ตำแหน่ง [illegible]

ผู้อนุญาต

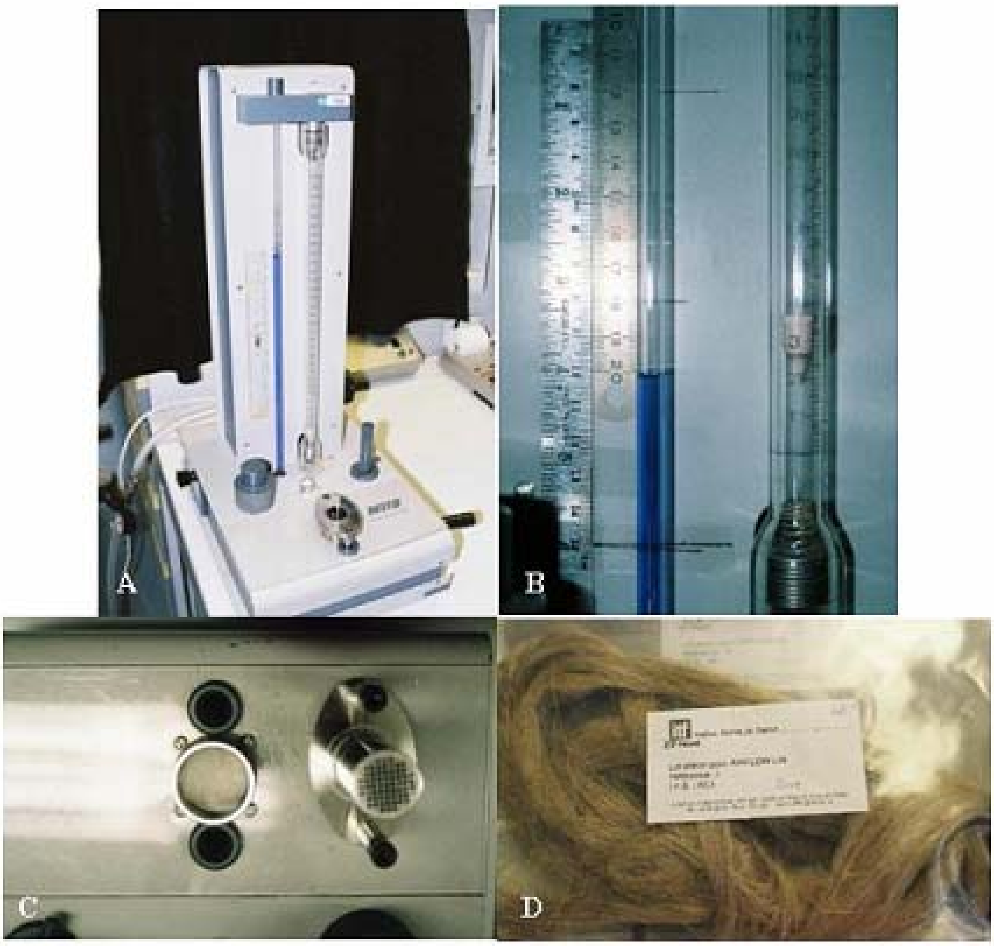
ปฏิบัติราชการแทนเลขาธิการคณะกรรมการอาหารและยา

<u>หมายเหตุ</u> : ผลิตซึ่งยาเสพติดให้โทษในประเภท 5 คือ "ปลูกพืชกัญชง" เพื่อศึกษาและพัฒนาศักยภาพพืชกัญชงเพื่อเป็นพืชเศรษฐกิจตามพระราชดำริ โดยเพิ่มเติมสถานที่ให้ปลูก 4 แห่ง คือ

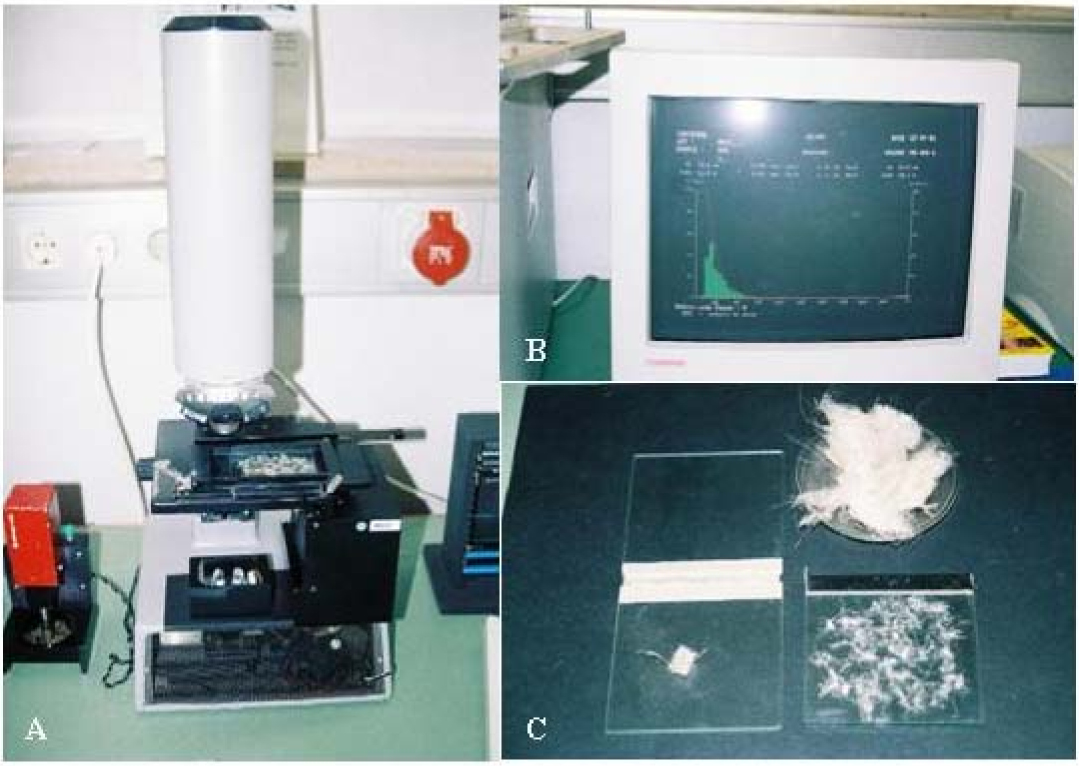
1. สถานีพัฒนาการเกษตรที่สูงตามพระราชดำริ ดอยอมพาย อ.แม่แจ่ม จ.เชียงใหม่ พื้นที่เพาะปลูก 5 ไร่
2. สถานีพัฒนาการเกษตรที่สูงตามพระราชดำริ ดอยแบแล ต.สบโขง อ.อมก๋อย จ.เชียงใหม่ พื้นที่เพาะปลูก 5 ไร่
3. สถานีพัฒนาการเกษตรที่สูงตามพระราชดำริ บ้านห้วยแม่เกี๋ยง ต.เมืองนะ อ.เชียงดาว จ.เชียงใหม่ พื้นที่เพาะปลูก 5 ไร่
4. สถานีสาธิตและถ่ายทอดการเกษตร ป่าไม้ สิ่งแวดล้อม ตามพระราชดำริ บ้านแปกแซม ต.เปียงหลวง อ.เวียงแหง จ.เชียงใหม่ พื้นที่เพาะปลูก 5 ไร่

Appendix Figure 2 The official permission of hemp cultivated by QSBG under the authorize of the Ministry of Public Health

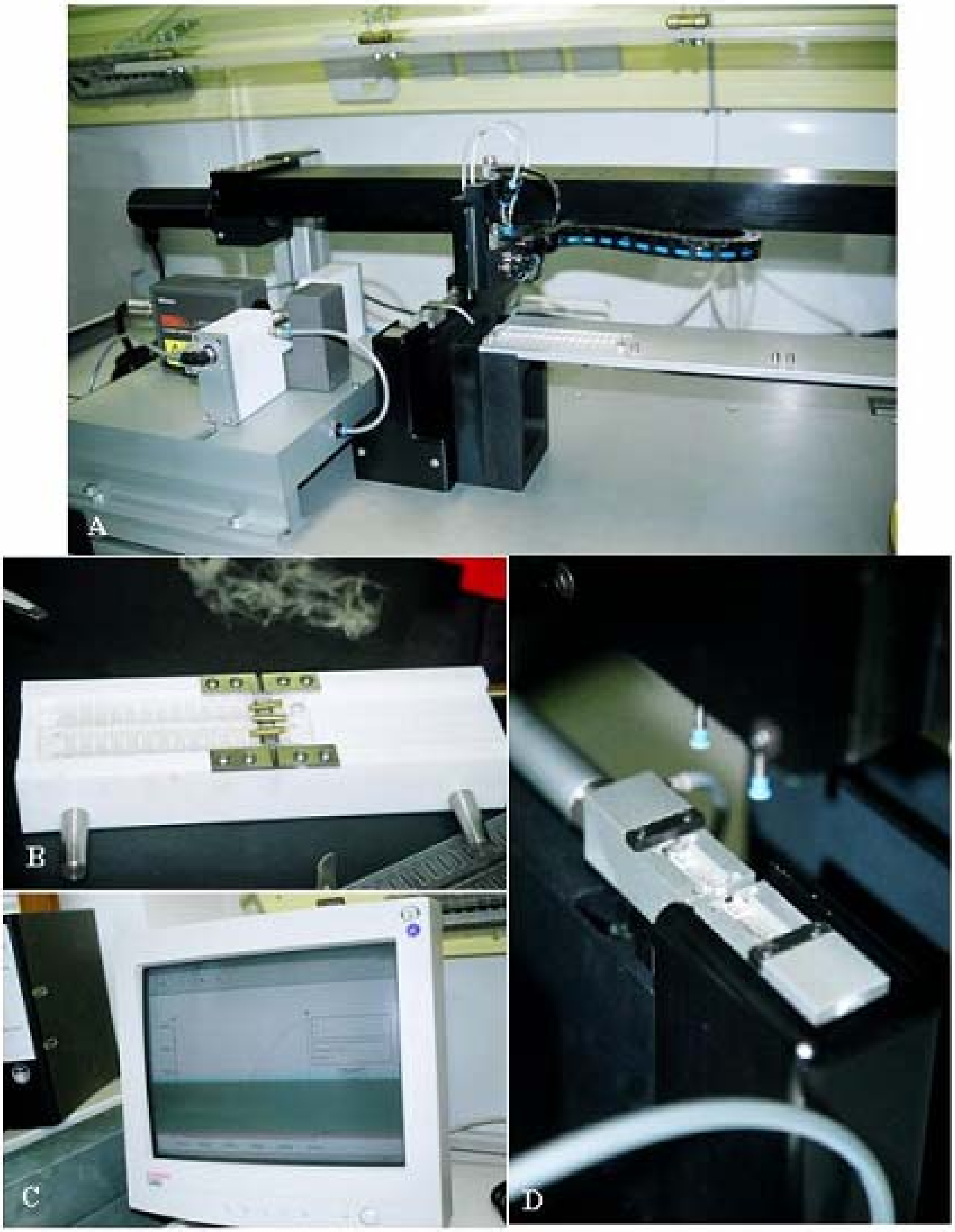
Appendix Figure 3 Fiber condition and preparation for fiber properties testing
A. Fiber condition at 20 °C 65 % RH at least 24 hrs
B. Course separator
C. Density of fiber for course separator at 6 g.m-1
D. Fiber after course separator



Appendix Figure 4 Airflow testing device
A. Airflow testing device B. Water and air column
C. Socket for fiber testing D. Standard fiber for calibration



Appendix Figure 5 Optical Fiber Diameter Analysis (OFDA)
A. OFDA B. The result from fiber testing
C. Fiber preparation



Appendix Figure 6 Diastron testing instrument
A. Diastron B. Fiber preparation C. testing result
D. Automatic transfered in testing system

Appendix Figure 7 Fibroliner and Almeter
A. Fibroliner B. Fiber preparation C. Combed fiber
D. Introduce fiber into Almeter E. Fiber for testing

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