BAMBOO MORPHOLOGY AND PHYSIOLOGY

PARTS OF THE PLANT

1.- THE RHIZOME

Bamboos are perennial plants consisting of a ramifying system of segmented vegetative axes which form a regular alternation of nodes and internodes. These segmented axes, according to their shape and position on the plant, have the following names:the *culm* or *stem* with the branches, which forms the aerial part of the plant and the *rizome system* with its *roots* which forms the subterranean part of the plant; and its structural foundation. The rhizome performs important functions in the life of the plant; it is the vital organ with which bamboo plants reproduce vegetatively or asexually through the branching of rhizomes. As an organ, it has the function of storage and transportation of nutrients. The culms depend on rhizomes for their growth, vigor and spacing on the ground.

Types of bamboos

As mentioned above, the tree species are commonly divided into two large groups according to their geographical position. They are:"softwoods" which naturally grow in the temperate zones, and "hardwoods" which grow in the tropical zones. These two groups have differences particularly in the anatomy of their trunks and their leaves.

Like trees, bamboos are also classified in two main types on the formation pattern of the subterranean part of the culm which also depends on the geographical position where they grows naturally. These main groups or types are: the *leptomorph or monopodial type* which grows in temperate zones; and the *pachymorph* or *sympodial type* which grows in the tropical zones. There is a subgroup or intermediate known as *metamorph* which is a combination of the two main groups, but has no relation with the geographical position.

The only thing that these two groups have in common is the morphology and anatomy of their culms and their growing process.The aerial part of these two groups is so similar that if the species are not known, it is difficult to recognize visually to which group they belong, unless the rhyzomes can be seen, because there is a great difference in the morphology and in the form of branching of the rhizomes between the two main groups and in the formation of the culm shoot, as can beseen in the Fig 1.1.

On the other hand, the two main groups of bamboos have differences in the number of chromosomes, which in the leptomorph type is 2n=48, and in the pachymorph type is 2n=72. The basic number of chromosomes is assumed to be 2n=18. Bamboos with low multiple chromosomes are considered to be of the advanced type and those with high ones are of primitive type. The basic number for most bamboo species is X=12, except for certain bamboo species (especially paquimorph bamboos). The difference in chromosome number and nucleous type can help to explain the systematic development, and clasification of bamboos.

In 1879, the Rivieres were the first to publish a clear distinction between the two basic forms of the bamboo rhizomes. They used the terms "*caespitose*", or "clumping " for pachymorph, and 'traçant" or "running" for leptomorph. In 1925 McClure introduced the terms "monopodial" and "sympodial" when he was living in China, and later, at the Smithsonian Institution, in Washington, he developed the concept of "leptomorph" and "pachymorph" respectively. Today the terms "leptomorph" and "paquimorph" are used in the Americas by the botanists and taxonomists, and the terms "monopodial" and "sympodial" in Asia.

a).-LEPTOMORPH RHIZOME

The leptomorph rhyzome is also known by the names of monopodial, traçant, indeterminate, and runnig bamboos. Bamboos with leptomorph rhizomes are usually distributed in temperate regions, such as Japan, Korea and China, where winters are severe. They are characterized by relatively strong frost-resistance, and consequently they can be cultivated at high elevations in the tropics.

Bamboos with this type of rhizome are represented in Asia by the genera *Arundinaria*, and *Phyllostachys*. The most cold-resistant are: *Phyllostachys praecox, Ph. propinqua, Ph. dulcis, Ph. iridenscens, Ph. nuda, Ph. angusta, Ph. aureosulcata,* and *Indocalamus*. In the Americas there are only three native species of leptomorph type which belong to the asiatic genus *Arundinaria,* and grow in the temperate zones of the southeastern of the United States up to 46° north latitud.

The subterranean part of the plant consists of two major parts, the *culm-base* with its root system and the *rhizome* system (See Fig. 1.1). The *culm- base* corresponds to the subterranean prolongation of the aerial culm and is conected to the rhizome by the *culm neck* . The internodes at the lower part of the culm-base are the shortest and there are usually 13-16.

The leptomorph rhizome has the creeping habit. It is long and slender, with a cylindrical or subcylindrical form, and a diameter usually less than that of the culms originating from it. The internodes are longer than broad, and they are generally shorter than those of the culm. They are typically solid with narrow lumen. Every node bears a solitary lateral bud and an encircling belt of roots at the node. Beyond the bud there is a longitudinal groove.

Most of the lateral buds are temporarily or permanently dormant. The majority of those that germinate generate single culms, directly, or rhizomes. But it is very difficult to determine whether a lateral bud of the rhizome is going to form a rhizome or a culm shoot when it is still dormant. The meristem generated in the lateral bud forms a culm neck which turns its apex upward forming the *culm base* and the culm shoot, and finally the culm proper. The buds on the *culm-base* can only grow into rhizomes and cannot grow into new culms.

The culms and the rhizomes grow in alternation all through the year. According to Ueda (1960), in temperate zones the rhizome grows during summer and autum when the temperature is relatively high, and the culms grow through winter to spring when the temperature is relatively low. The rhizome begins to develop after the new culm shoots have attained their full growth and the new branches and leaves have developed. This usually starts in March after the soil temperature rises up to about + 5^{0} C. The rhyzome grows fastest in August and September, and ceases to grow gradually from November onwards.

The rhizome shoot is slender and runs its apical meristem forward, parallel to the ground surface. The elongation of a leptomorph rhizome shoot depends on the activity of two meristems: the *apical meristem* at the terminal end of the rhizome, and the *intercalary or intermediate meristems* located between the internodes of the rhizome. The apical meristem consists of tunica-corpus and its derived meristem. The cells of a derived meristem differenciate into sheaths, buds, primordial roots and vascular bundles. The original slanted bundles and enlarged parenchyma cells form a new node at the young sheath position, and divide the derived meristem into several intercalary meristems.

The growth of a rhizome is mainly determined by the stretching action of a terminal portion of the rhizome which consists of 14-16 actively elongating internodes. The internodes of the streching portion elongate according to the rhythm of "slow-fast-slow" from back to front. The latter sections of the stretching portion mature and stop stretching. As the growing season proceeds, the apical meristem produces new nodes and internodes continnuously. The new internodes formed by the meristem at the terminal end, act in succession replacing the former part of the stretching portion. The rhizome tip continues to grow .

The apical meristem of the rhizome shoot is tightly embraced layer by layer by hard thick sheaths and is sharply pointed like a borer which can penetrate through the hard-textured soils or the gravel gaps with driven force generated from the internodal elongation. The rhizome shoot does not necessarily maintain a horizontal position nor does it fallows in a fixed direction but it may twist, bed, shrink, elongate or wind with the topogragraphical and soil conditions. It grows in all directions, and forms a complex interwined network. It may run to considerables distances and send out many single culms that appear on the ground scattered at certain distances every year.

Ueda (1960) made extensive excavations of the leptomorph rhizomes of several species of Japanese bamboos,

Fig. 1.2 RHIZOME SYSTEM OF THE LEPTOMORPH TYPE

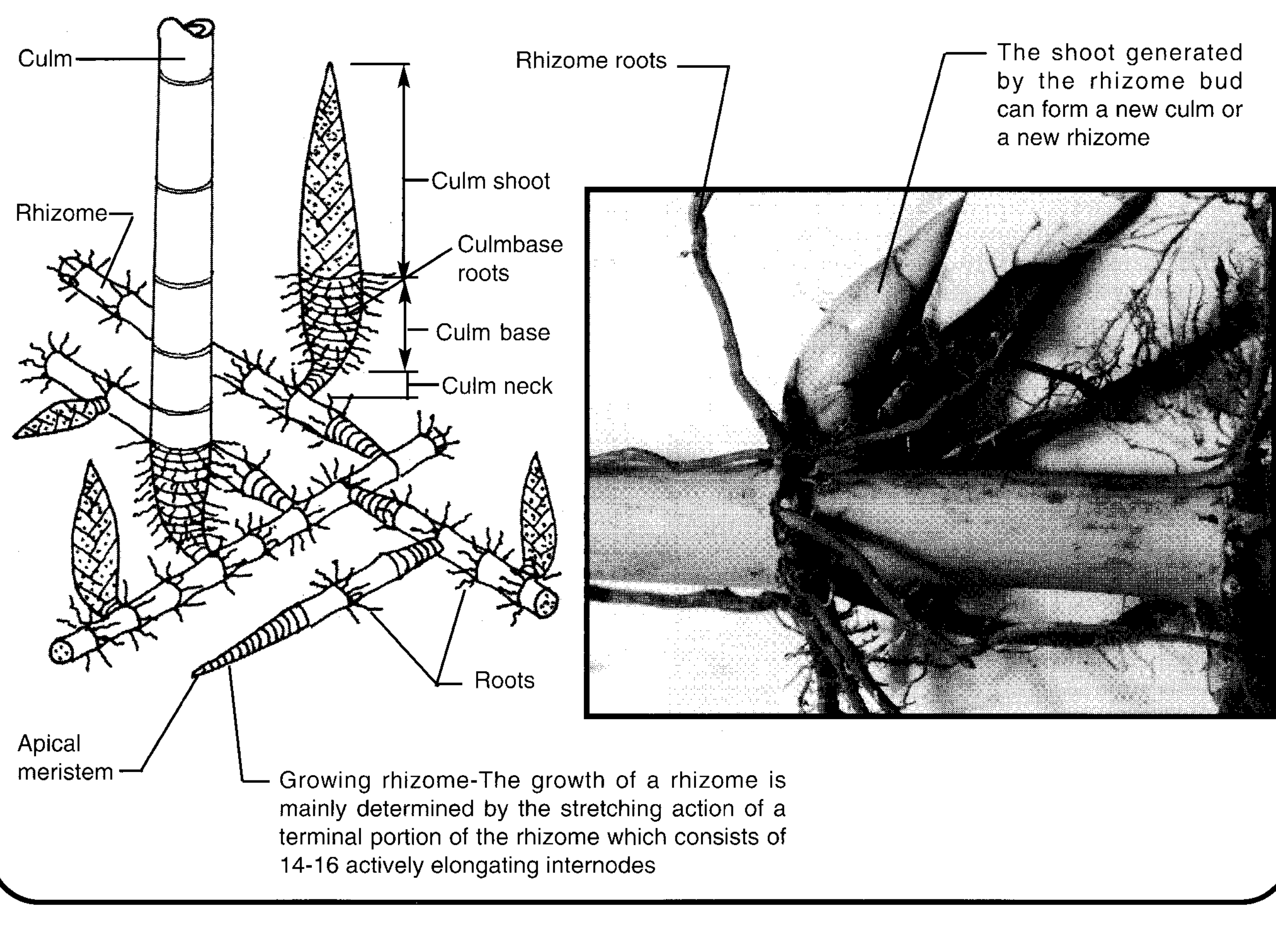


Fig.1.3 *The soil has been removed by Ueda in order to show the intrincate system of rhizomes which form a network just below the surface and conect most of the standing culms. This means that the whole grove is one plant.*

plotting the pattern and rate of their extension. He found that the total length of living rhizomes per 0.1 ha. in bamboo groves of *Phyllostachis reticulata* was from 6,300 to 18.740 meters; in groves of *Pleioblastus pubescens* from 47,000 to 57,920 meters.

The rhizome neth under the ground prevents landslide and collapse of river bank and hill sides where there are an erosion problems. Bamboo cultivation for the protection of river banks was recommended in Japan in the sixteen century. This is also the reason why a bamboo plantation is considered a safe refuge when an earthquake takes place.

The depth that the rhizome travels on the ground also varies with the type of bamboo. The horizontal growth mostly take place in the upper soil layer between 10 -30 cm in depth, where water, heat, and air are easily available. Very few rhizomes grow deeper than 50 cm.

The annual extention of the rhizomes ranges from 0.30 to 0.70 meters in small bamboos and about 4- 6meters in large culm bamboos such as *Phyllostachys bambusoides* (Madake). Their length varies according to species and habitat. The growth period is shorter in areas of high latitud and high elevations than in low latitudes and low elevations. The same is the case on shaded slopes compared to sunny slopes.

According to Takenouchi (1932), in special conditions, the rhizome top goes out of the earth or soil and some continue to grow upwards to become bamboo shoots. Some, however, enter the earth again after stretching a bit on earth, forming the socalled "*jumping rhizome*" like a bow. Jumping rhizomes tend to appear where the upper layer of forest soil is hardened and impervious. The same author points out that when the rhizome is injured or cut off, the nearest bud behind the injured part develops into a new rhizome, which continues to grow in the same direction of the parent rhizome.

The longevity of the rhizome also varies with the specie of bamboo. According to Takenouchi (1932), the rhizome of *Pleioblastus simoni* (Madake) and *Phyllostachys nigra henonis* (Hachicu) continue to function actively to the third year, after which they gradually decline in vigor and from about the fifth year they slowly go into decay and die in the seventh or eighth year. In *P. edulis* (Mosochicu) the period of highest activity of the rhizome is from the third to the sixth year. In the eighth or ninth year decay sets in, and kills it in the twelfth or thirteenth year (Takenouchi 1939, Wen et all. 1981. ;Xiao 1991).

Direction which the leptomorph rhizome takes when it starts its growth

The following information was found in the Chinese book "Treatise on Husbandry" *(Chi min yaoshu*), written by Chia Suniu in the 5th century: "*Owing to the nature of the bamboo it has a tendency to spread its rhizome growth in a southwesterly direction. Therefore they are usually planted in the northeastern part of the garden or grove. After several years they will spread in their growth until the culms fill the whole garden. There is a tradidition that if the bamboos are planted on the western side of the house their roots will spread, covering the ground until they reach a neighbor's house on* the west."

Taking into account that China is located in the northern hemisphere, I think that it is very important to experiment this interesting theory south of the Ecuador, (in the southern hemisphere), in order to see if there is any change in the direction the rhizome takes when it starts its growing process.

b).-PACHYMORPH RHIZOME

This type of rhizome is also known as *clump type*, sympodial, caespitose and determinate. It is typical of tropical zones of the Americas, Asia, Africa and Oceania. It can not withstand freezing temperatures. Bamboos with this type of rhizome are represented in the Americas by genus *Guadua,* and in tropical Asia by the genera *Dendrocalamus* and *Bambusa.*

The morfology and growing process of pachymorph rhizomes is different from that of the leptomorph rhizomes and has the following characteristics: The culm-base does not exist in the subterranean part of the culm and the aerial culm is generated directly by the rhizome, which, in this case could be considered as the culm-base.

The rhizome is solid, with roots on the lower side, the shape is usually more or less curved, and the internodes are broader than long. The maximum thickness of this rhizome is somewhat greater than that of the culm that generates. The lateral buds of the rhizome are dome-shaped and generate only rhizomes. The rhizome is narrow at the neck where it is attached to the mother rhizome, and thick and broad at the other end whose apex protudes out of the ground and grows into a new culm shoot which generates the culm. In the following year a new rhizome grows, which is is generated by the meristematic zone of one of the lateral buds of the mother bamboo.

The bud protrudes forming first the new rhizome neck, and then the shoot of the rhizome itself, which is covered with sheaths. In the rhizome, the sheaths have the function of protecting the tender apical meristem by forming a sharp-pointed resistant shield around it to protect it when the rhizome is pushed through the soil by the elongation of the rhizome internodes during its growing process. Once developed, (in two or three months, depending on the species),the new rhizome turns its distal end or apical meristem turns upward and forms the culm shoot.

In the tropics new culm shoots or sprouts begin to appear after the beginning of the rainy season. They protrude from the ground as scaly cones covered with sheaths. In warm regions with precipitation at frequent intervals throughout the year, the growth is often more or less continuous.Once the culm-shoot is formed, the apical meristem stops its function and the intercalary meristems located between the nodes start the growing process of each one of the internodes starting from the lowest one.

In pachymorph species, the distance between the culms depends on the length of the rhizome neck and on the position of the rhizome. When the rhizome neck is short, and the position of the rhizome is almost vertical, densely caespitose clumps of bamboo are formed, as in the genera *Bambusa* (*Bambusa vulgaris*), *Dendrocalamus* and some species of genus *Guadua* such as "Guadua brasilera", which is cultivated in Costa Rica .Fig 1.6 B. When the neck of the rhizome is long and the rhizome has an almost horizontal position, as in genera *Melocana, Fargesia*, and *Guadua angustifolia*, the culms grow separatelly and open clumps are formed. According to Arbelaez (1996) the minimum and maximum separation beetwen the mother bamboo and the new culm shoot in a clump of *Guadua angustifolia* was 0.85 to 1.70 meters. In Asia there are species of *Melocanna*

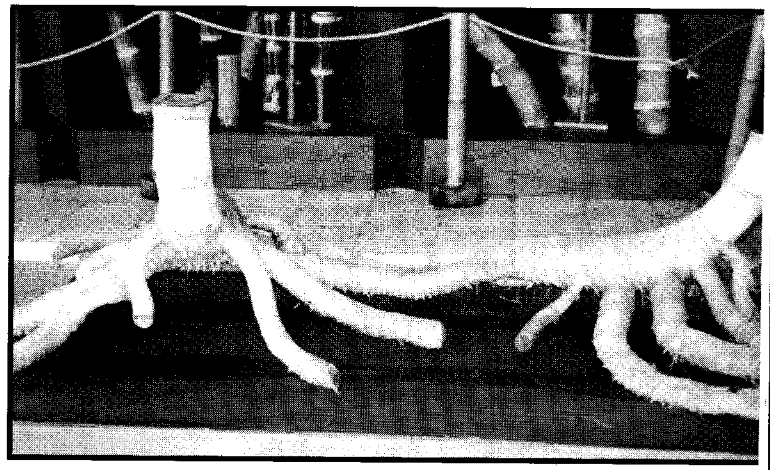


Fig. 1.5 *Rhizomes of Guadua angustifolia in which the length of the neck, the separation of the culms, and the short necks developed by the rhizomes for providing a colective foot to support the heavy culms can be seen.*

(pachymorph) in which the culms are separated by more than 3 meters.In some species the neck and the rhizome grows almost vertically and looks like part of the culm (Fig. 1.6).

In general, the pachymorph rhizome system is superficial and does not penetrate more than 0.60 meters below ground level. The longevity of the pachymorph rhizome varies with the specie of bamboo.

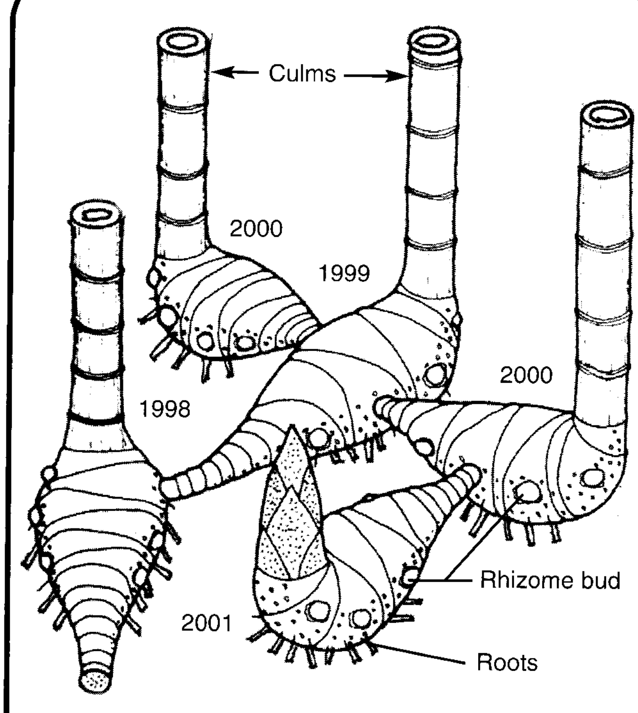


Fig.1.4 *Rhizome system of pachymorph type of tropical areas. In this case, the rhizome bud only generates new rhizomes with their respective culms.*

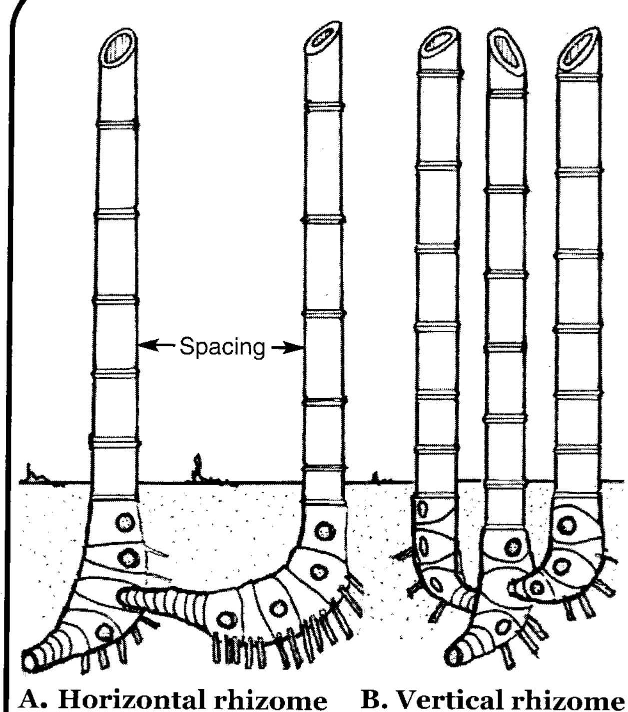


Fig.1.6 *The spacing between culms depends on the length of the rhizome necks and the vertical orientation of the rhizome, as in the case of G.brasilera.*

According to Deogun (1936), the rizhome of *Dendrocalamus strictus* show signs of deterioration in their fifth year, so one would not expect new culms from rhizomes of culms five years or more in age.

According to Bahadur (1979), the rhizome of *Dendrocalamus hamiltonii* with slight trimming and dressing is an exact replica of a rhinoceros horn which fetches a fabulous price as an aphrodisiac. Perhaps only an expert can identified the imitation rhino horn from the real one. The nefarious use, however, needs to be discoraged. Be careful!

C.-METAMORPH RHIZOME

Known also as amphipodial, the metamorph rhizome includes those species which have the capacity to produce both typical pachymorph and typical leptomorph rhizomes in the same plant. In America this is a characteristic of *Chusquea fendleri (Fig. 1.7)* and others species of this American genus. In Asia, according to Tian (1989), *Bashania fargesii*, from China, produces shoots in spring, summer and autumn, but 98.9% of its total shoot output is produced in spring.

The peak period of shooting comes when the soil temperature at the depth of 10 cm underground reaches 10° to 12°C. The formation and emergence of shoots are closely related to the altitud. With every rise of 200 m in elevation, shooting begings by 13 - 15 days later.

Both the rhizome bud and culmbase lateral bud of this bamboo come up into shoots due to its amphipodial rhizome system. This results in the mixed distribution of shoot in the stands. The shoots developed from culmbase side buds are more and better than those from rhizome buds. The rhizome system keeps its shooting power for more than 15 years, while the side buds only 5- 6 years. The buds of 4 - 5 years old rhizome is most productive. The shoots attained their full height in 90 days.

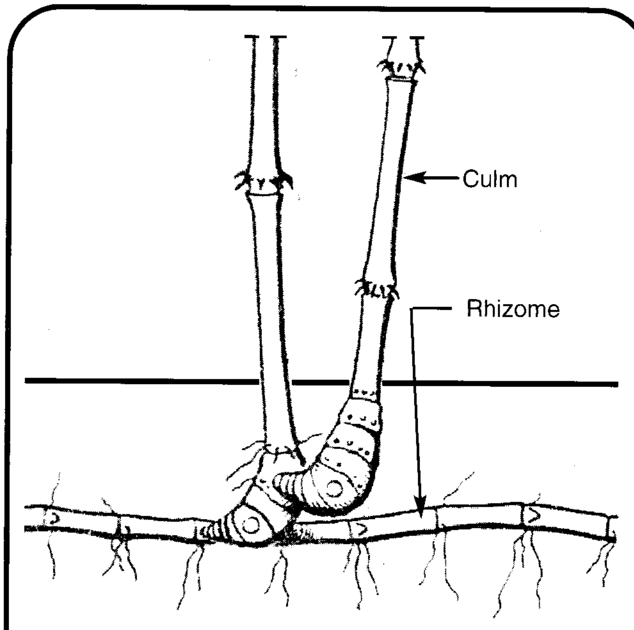


Fig. 1.7 *Metamorph rhizome of Chusquea fendleri. This kind of rhizome can produce leptomorph and paquimorph rhizomes in the same plant.*

2.-THE CULM

As mentioned above, in species with leptomorph rhizome, the culm consist of two parts: the aerial part or culm proper and the subterranean part of the culm known as *culm base* with its root system, which is conected to the rhizome by the *culm neck*.

In species with pachymorph rhizome, the culm base with roots does not exist and the aerial part of the culm is conected directly to the rhizome, which in this case could be considered as a culm base.

Formation and growing of the culm base and culm shoot in species with leptomorph rhizomes

In species with leptomorph rhizomes the culm is generated from one of the apical meristems located in one of the buds of the rhizome, which protrudes and forms the culm neck and then it swells until it becomes a long shoot or sprout, thicker than the rhizome and covered with sheaths, which looks like two cones joined by their bases (See Figure 1.9). Compressed in the short lower inverted cone,this shoot includes 13 to 16 nodes, which once developed form the culm base. The upper cone, which is longer, than the lower one, corresponds to the culm shoot, which once elongated becomes the culm(See Figure 1.8).

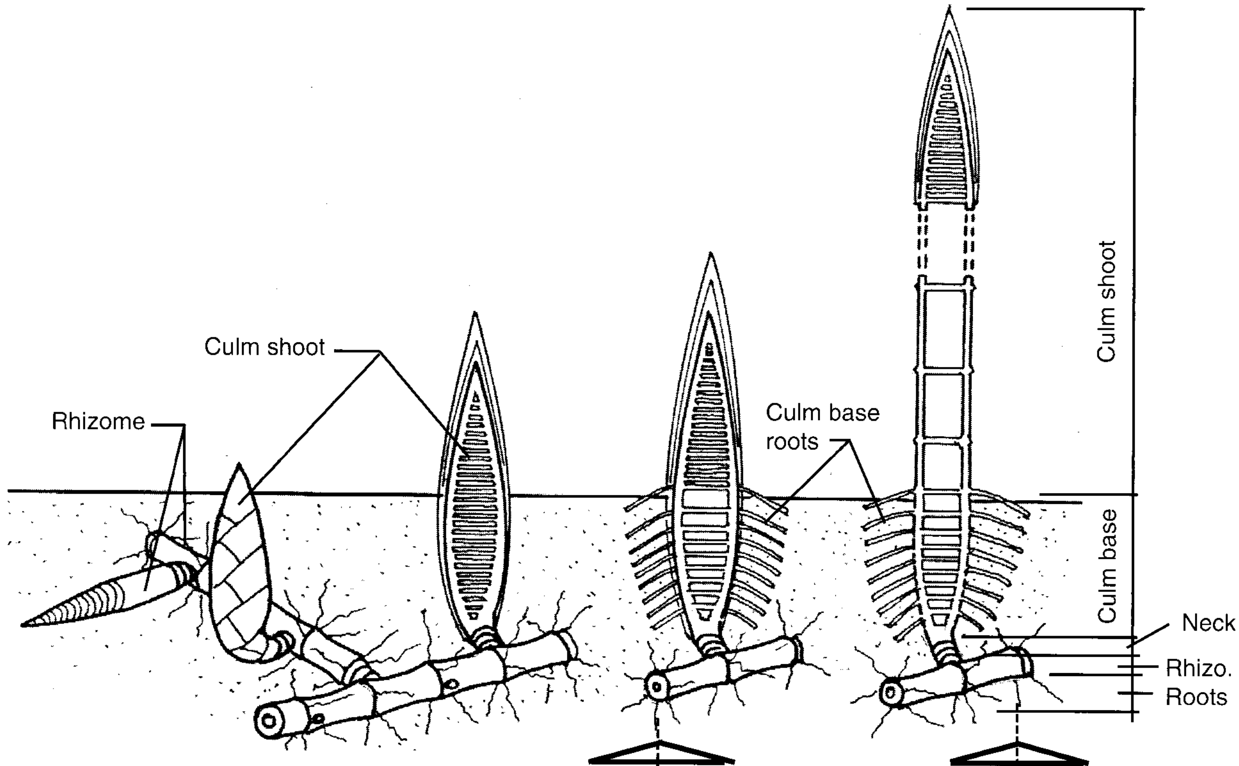
An interesting feature of this long shoot, is that all the nodes of the culm base, and the nodes of the culm shoot that once elongated will become the whole culm, (the aerial culm and the culm base) are compressed into it. In other words, most of the nodes of the culm lie flat one on the top of the other like a pile of plates, with the pith betwen them larger and thicker on the bottom, and tapering off to the smaller and thinner at the top near the growing point or apical meristem.

Once the apical meristem have finished the formation of the whole culm shoot, it stops its function and the intercalary meristems located between the nodes of the culmbase, start the construction or elongation of their internodes The elongation of the internodes of the culm base is very short because its function is to rise the maximum diameter or base of the culm shoot (which separate the culm proper from the culmbase) up to the ground level. Once the growing proccess of the culm base has been completed, and the base of the *culm shoot* is already located at the ground level, starts its growing process.

Growing process of the culm shoot in species with leptomorph and pachymorph rhyzomes.

The growing process of the culm shoot or aerial culm, is the same for species with leptomorph and pachymorph rhizomes, but is different of that of tree trunks. Unlike trees the bamboo culm does not grow in diameter and the growing process of the culm is carried out by two kinds of meristems known as *apical meristem* and *intercalar meristems*. The *apical meristem* is in charge of the formation of the rhizome shoot, culm base and culm shoot, and branch shoots. The *intercalar meristems* located between the nodes, are in charge of the growing of each of these parts which have been formed by the apical meristems, including the growing

Fig.1.8 FORMATION AND GROWING PROCESS OF THE CULM BASE AND CULM SHOOT IN LEPTOMORPH BAMBOOS



of the walls of each one of the internodes of the culm shoot starting from the lowest.

Once the formation process of the culm shoot is completed by the apical meristem, it stops its function and the growing process or growing of the internodes of the culm shoot continues. Thus each internode has its growing zone or *intercalary meristem*, between the nodes and consequently each internode grows separately, starting from the basal internode The. culm elongates joint by joint until it reaches its maximum height. The culm shoot ceases growing only when the last internodal growth is completed. It can be confirmed that the growth of each internode is completed when the culm sheaths peel off slightly from their base or sheath scar.

Sprout emergence of tropical bamboos is commonly at the onset of the rainy season and in temperate bamboos it is in spring. Nevertheless, it can vary according to the species, the vigour of the mother bamboo, and the environmental condition of the site Even in one bamboo grove, however there are variations of 50 to 60 days between early and late sprouting.

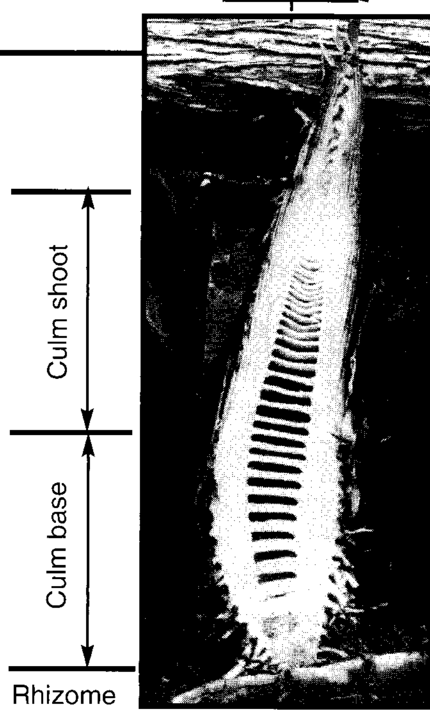


Fig.1.9 *Longitudinal section of a shoot or sprout of Phyllostachys pubescens (Ph. edulis) showing most of the internodes of the culmbase and culm shoot compressed, and the rhizome in the lower part. (Young 1961).*

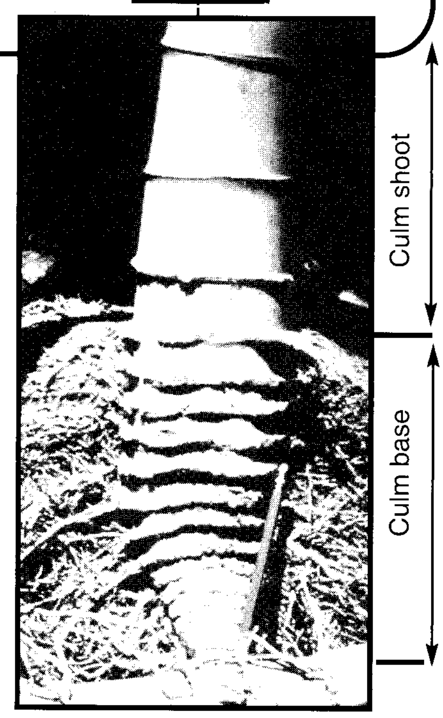
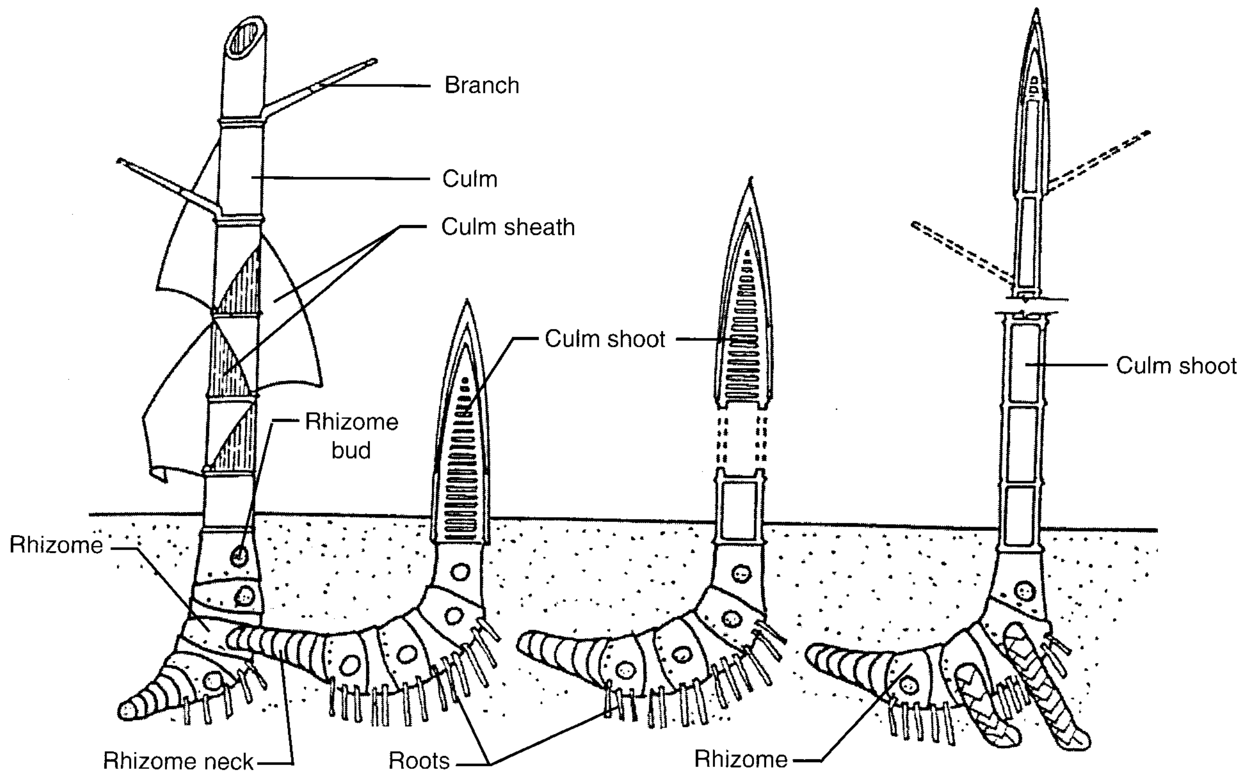


Fig.1.10 *The subterranean part of the plant which includes the rhizome, the neck, the culm base, and part of the culm or aerial part. The front roots of the culm base have been removed in order to show the internodes of the culm base. (See bamboo carving).*

Fig. 1.11 GROWING PROCESS OF THE CULM SHOOT IN PACHY MORPH BAMBOOS



The growing period is longer for early sprouts and shorter for the late sprouts. Early sprouts tend to develope into larger culms with superior quality, while late sprouts develop into smaller culms with inferior quality. When the precipitation is low the number of sprouts decreases. (Ueda 1960, Lu et al 1989).

In Northern India *Bambusa arundinacea* and *Dendrocalaus strictus* send up their new culm shoots in June or July when the south west monsoon rains begins, but in South India the new culms shoots appear in September or October with the northeast monsoon rains.

According to Kurz (1875) in some provinces of India there is the belief that a thunderstorm is necesary before the bamboo can shoot. Perhaps this is due to the coincidence of the rainy season and storms. This is confirmed by Wang (1993) who says that the Chinese specie *Phyllostachys praecox* ,sprouts when thunder occurs in early spring so it is called *Ph. praecox*, which means"thunder shoot".

When the culm shoot of giant bamboos appears on the ground covered with sheaths and it has a height of about 30 to 40 cms, the culm base has reached its maximum diameter, and thereafter this will never increase. The culm shoot starts growing by elongation of the internodes, starting at the lowest internode. At first they grow slowly, then very fast and finally very slowly again until they complete their full growth. In species of pachymorph type the whole growth takes about 80 days, and in giant species such as *Guadua angustifolia*.up to 180 days. In species of the leptomorph type, it takes 30 days for the small species and up to 130 days (4-5 months) for the giant species Then it develops the branches and leaves and becomes a mother bamboo before completing the first year.

If the apex of the growing culm shoot is cut off, the elongation of the remaining portion does not stop. This shows that when the intercalar meristems are activated, the apical meristem is deactivated. Once the full growth of the last internode is completed the height of the culm do not encrease any more. At this point, the growing process of the lateral branches of the culm which are generated from the meristematic zone located in the culm buds (axillary meristems) starts.

The branch shoot emerge from the buds located on alternate sides of the culm just above the sheath scar at successive nodes, and they elongate in the same way as the culm. Once the full growth of the last internode is completed, development of the leaves starts.

Daily growth of the culm-shoot

According to several studies, the daily growth correlates positively with temperature and negatively with humidity. In most of species of leptomorph type such as those of genus *Phyllostachys* which sprouts in the spring in Japan, the elongation of the culm sprout occurs more during the day than during the night. However, the pachymorph bamboos in tropical regions are the opposite. For example, *Dendrocalamus strictus* grows twice as much during the night as during the day, and there are species such as *Bambusa oldhami* which grows three times more during the night than during the day.

Jin (1989) reported that in the southern region of jiang, China, the total growth of *Bambusa oldhami* lasted 171 days

(65 days for underground growth and 106 days for aboveground growth). The total growth in this time (or accumulative growth) was 712 cm and the mean daily growth was 6.71 cm.

According to the updated records mentioned by Ueda (1960, 1981) the greatest growth rates of a bamboo culm shoot per day (24 hours) are the following:

a) **91.3** cms by *Bambusa arundinacea* observed at Kew Garden in England in 1855.

b) **88** cm by *Phyllostachys edulis (Ph. pubescens)* which K. Shibata observed at Koishikawa Botanical Garden in Tokio in 1898.

c) **119** cm by Moso-chiku, *Phyllostachys edulis* (diameter of 16 cm), observed on May 24, 1956 by Koichiro Ueda in Nagaoka, Kyoto Prefecture, Japan.

d) **121** cm by Madake, *Phyllostachys reticulata* (12 cm in diameter) which is the maximum record of daily elongation (24 hours). It was measured by Koichiro Ueda on the outskirts of Kioto on June 23, 1955.

In Colombia, the maximum elongation observed in *Guadua angustifolia* has been 30 cm in 24 hours. I have observed only elongations of 11 to 15 cm. (Hidalgo 1978).

CHARACTERISTICS OF THE CULM

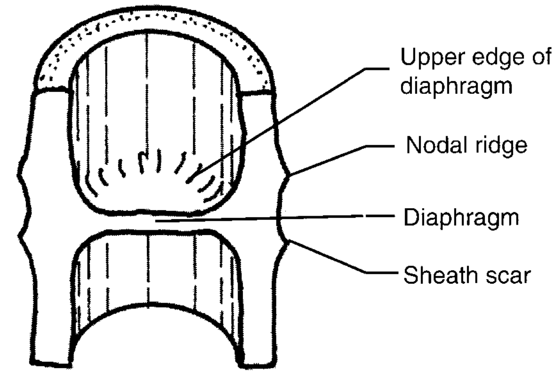
Once the culm shoot has finished the elongation of the last internode it becomes a culm. The culm or stem of bamboos consists of a regular alternation of nodes and internodes, generally hollow, which together with the hard, thick and cylindrical wall gives the culm great mechanical strength.

The nodes are important centers of morphogenetic activity and intercalary growth. Roots and branches emerge only at the nodes and in many species they may be swollen. The culm node consists of sheath scar, the supra-nodal ridge, the diaphragm and the intranode. In most species culm buds emerge from the midle part upwards on alternate sides of the culm just above the sheath scar at successive nodes, but in *Guadua angustifolia* culm buds emerge from the lower to the top part of the culm

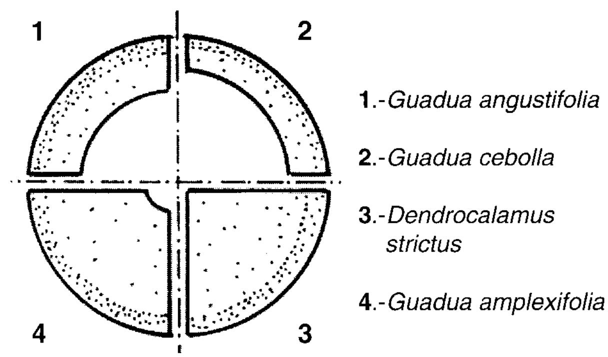
According to Yulong & Liese (1996) The intranode (between the nodal ridge and the sheath scar) can vary in length between 3-10 mm. The nodadl region of bamboos revealed that the anatomical structures are basically similar between pachymorph and leptomorph species. Most of the bamboos have distinct nodes, which differ in shape among the species. Some pachymorph species develop dense air roots around the nodal ridge at the bottom part of the culm. The form of the diaphragm can vary along one culm. It may be plane or its central part formed upwards or downwards or it may even be folded. Furthermore, the nodal structure is important for the liquid movement during drying and preservation as well as for the physical and mechanical properties of the culm.

The internodes are delimited by a sheath scar, which marks in the exterior surface the insertion of the culm sheath or culm leaf to the culm. The internodes are shorter on the bottom and top of the culm and are generally longer at the middle part of the culm. For example in *Guadua angustifolia* the average lengths are : 12-24 cm. (bottom), 40 cm. (middle) and 30 cm (top). There are species such as *Pleioblastus longinternodios* in which the length of the internodes varies between 70 -94 cms. (Yang 1989). In some species the internodes of the base are very long as in *Dendrochloa distans* (tamyinwa) of southern Burma, which may reach a length of 1.80 meters.

Fig. 1.12 - Nodal and internodal morphology



A. Nodal Morphology (Liese, 1998)



B. Morphology of internodal bamboo sections

Culms of the same clump and with the same high do not have the same number of internodes In Colombia, I have found in two culms of *Guadua angustifolia* with lengths of 17,13 m and 17,36 m., 80 and 76 internodes respectively, and in two culms of 18.40 and 19 meters, 82 and 78 internodes respectively. This means that there is no relationship between the height of the culm and the number of internodes. Some of the internode characteristics are the surface texture, the combination and pattern of colors, and the type of pubescense. The internodes are usually glabrous and smooth or rough and hairy, becoming glabrous at maturity. When young they are covered with a waxy coating on top. A characteristic of many bamboos is the appearance of a white exudate on the surface of the culm internodes.

Color of the culms.

Not all the bamboo culms are green, some are green with yellow stripes such as *Guadua angustifolia* var. bicolor, which is the most beautiful specie of the Americas. Other culms are yellow or yellow with green stripes such as *Phyllostachys viridis sulphurea* and *Bambusa vulgaris* var. *vittata*. It is important to point out that the yellow and green colors of this specie were chosen for the Brazilian flag. There are species that are black like *Phyllostachys* *nigra,* or black with yellow stripes like "guadua rayada amarilla" (still not identified) of Colombia. Also, there are small white and red species.

According to Tai Kai-chi (265-306 A.D.), in China there were red and white giant species such as the *Kuei chu* (cassia bamboo), whose culms were red and the largest one had a circunference of "two chi" (0.66 mts). The white specie known as Huang chu (Bushy bamboo), "has a skin as white as hoar frost". The white specie which was known as Pai lu chu, (white deer bamboo) has the characteristic that "in the hot summer season, the white skin and flesh both become red". This variety is found in Wuling (Changte).

Natural culm forms

Most of the bamboo species have round culms in section but there is also a specie which has natural square culms, and in ancient China there were also species with triangular culms. It is important to point out that the culm can be deformed artificially, transversally and longitudinally as we will see in other chapter. The following are some of the unusual bamboo forms:

1.-The natural square bamboo from China

According to Porterfield (1925), the first information about the square bamboo *Tetragonocalamus angulatus (Phyl-lostachys quadrangularis)*, appeared in a Japanese book "Mo Ku Kin Yo Siu "(Trees and shrubs with ornamental foliage) published in Kioto in 1829. It is said that this bamboo was introduced from China.

The earliest references to square bamboo (Fang chu) in Chinese literature, says that in the year 128 B.C. in Szechuan, walking-stiks or staves made from square bamboo of Chiung which never breaks were used. The Chinese atribute the squarness of this peculiar bamboo to supernatural powers.

The Ningpo Gazetteer say that a Ko Hsien (fairy) prepared some elixir of life which he drank and ascended the mountain called Ling feng in Ting hai, where he planted some chopsticks which grew and developed into bamboo with square form. (Kuang-chi, 1640)

This bamboo grows from 3 to 10 meters high. The squareness is not so evident in smaller and less mature culms as it is in the older and specially the larger culms. This specie is valued chiefly as an ornamental garden plant. It was first discovered in the form of staves being used by Buddhist monks and village elders. The smaller and less squarish culms were used for opium pipes, and the still smaller ones for tobacco pipes. (See How to make square bamboo).

2-Internodes with the shape of bottles

These are found in the species: *Dendrocalamus latiflorus Munro* var. *lagenarius* Lin. and *Bambusa ventricosa* McClure. This is one of the most beautiful bamboos.

3.-Triangular. In the book *Kuan Chun Fang Pu,* published in China in 1707, there is a description of an ancient Chinese bamboo known as *San leng chu* (Triangular bamboo). *The culms of this variety had three angles.*

4.-Flat culms. In the same book the *Pien chu* (Flat bamboo) is also mentioned. According to Sun pu this variety was grown in large numbers in the Kuang lu shan, a mountain between Hsing-tzu and Chiu-chiang distiricts in Kiangsi). The culm and the nodes are flat and very long. It is said that this variety has been flattened into this form by the Buddist God. Probably this specie is the same square bamboo or a similar variety.

Freak culms

There are several bamboo species that suffer a typical deformation during their growing proccess. These deformations are known as freeks and make them valuable pieces used for decorative purposes. The most important variations are the following:

1).-Turtle shell bamboo.-In Chinese this deformation is referred to as Loo Hann because of its strangeness and rarity and it is regarded as a vehicle of divinity. In Japan it is known as Kikko-Chiku. It is considered by botanist as *Phyllostachys pubescens* var. *heterocycla* form subconvexa.

2).-Budda's face Bamboo. This is known in Japan as Butsumen-Chicu . It is an unusual form of *Phyllostachys pubescens. (Ph. edulis)* For many people the form of turtle shell and budda's face bamboos are not clearly distinguished.

In both cases, the internodes of the lower part of the culms of this two forms are greatly reduced in length and are arranged obliquely in a zigzag fashion. In Budda's face the oblique arrangement of the nodes is such that each node almost form right angles with the nodes immediatelly above and below it.

3).-Spiral bamboo or "aobadake". *Pleioblastus gramineus* f. *monstrispiralis* (Rasetsu chiku) . This specie has rhizome metamorph (anphypodial), culms 2-4 meters height and a diameters of 1-4 centimeters. The culms that shoot out with leptomorph branching are normal types, and many of the ones with pachymorph branching are abnormal. The long spiral culms are used for decoration. (Okamurka 1986).

Abnormality of the internodes

According to Zang and Ma (1991), plant species reproduced via asexual means are genetically stable, yet due to their heterozygote nature, some variations and mutations might occur during the process of asexual reproduction, under certain specific conditions. Mean while , due to the extensive existence of changeable genes, some individual become the chimaera of mutated and unmutated genes.

It is not unusual for vegetative plants and their progeny to produce diversifications, variations and mutations. *Ph. edulis var. heterocycla* which has a very high ornamental value is a specie resulting from a virus infection of normal *Ph. edulis* which causes abnormality of the culm's internode.

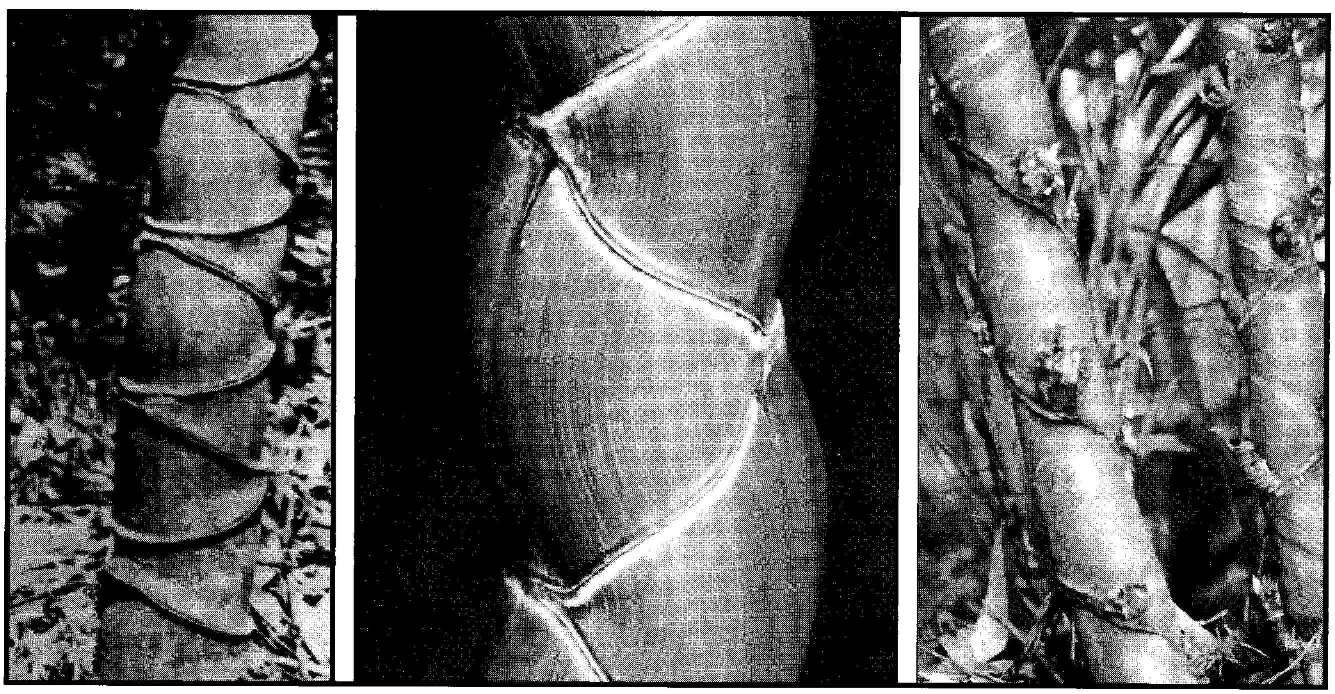
Due to the fact that this mutation occurs only under certain specific conditions, reverse mutation might occur when the specific conditions disappear. Other examples include *Bambusa vulgaris cv. wamin, Bambusa ventricosa cv. nana,* and *Phyllostachys aurea* which have swollen and inclined internode at the base of the culm.

Fig.1.13 **NATURAL SHAPES OF BAMBOO CULMS**

A B C

A. -*Natural square bamboo* (*Tetragonocalamus angulatus*)
B.- *Dendrocalamus latiflorus Munro var. lagenarius* Lin.
C.- *Bambusa ventricosa*

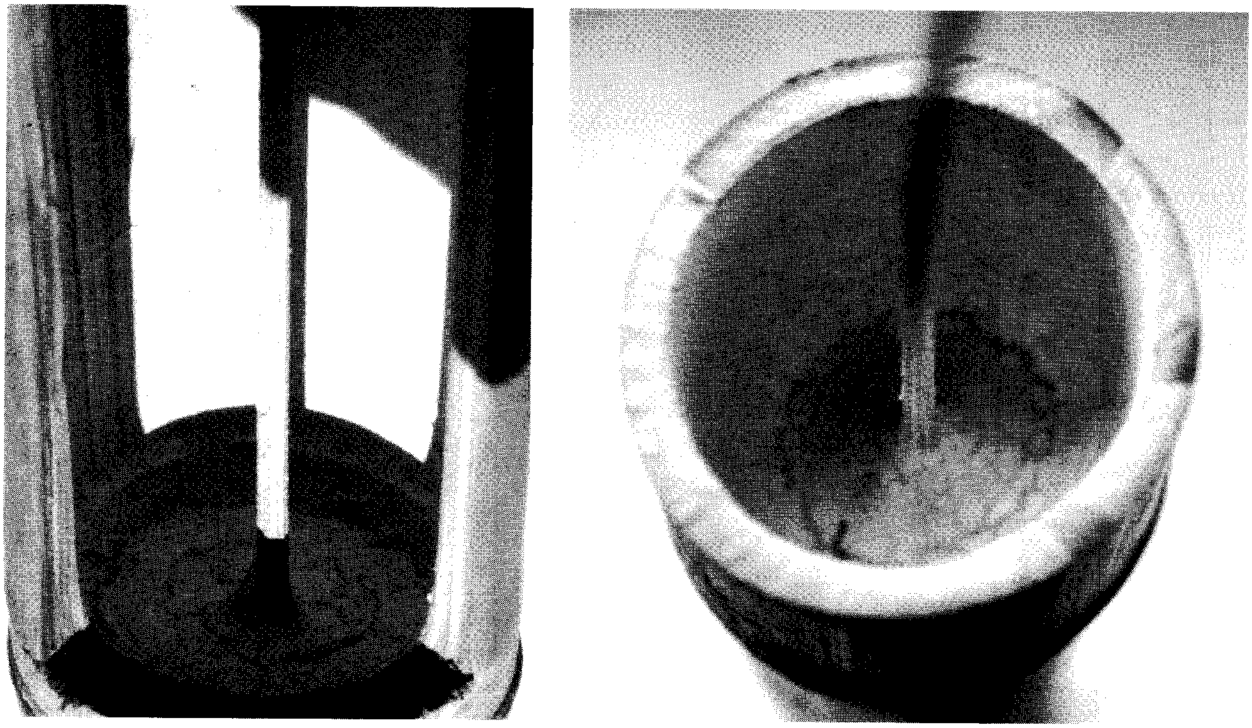
Fig. 1.14 **FREAK CULMS**



A B C

A The turtle shell *(Phyllostachys pubescens var. heterocycla form subconvexa).*
B -Budda's face bamboo *(Phyllostachys pubescens).*
C*-Spiral bamboo (Pleioblastus gramineus f. monstrispiralis) (Rasetsu).*

Fig 1.15 **ABNORMALITY IN CULMS OF *Guadua angustifolia***



On the Cotove farm belonging to the Nacional University in the State of Antioquia, near the city of Santa Fe de Antioquia, there is a small plantation (0.33 hectares) of Guadua angustifolia According to Anacilia Arbelaez, in the central part of the internodes, most of the culms have like a wooden rod with an average diameter of about 5 mm which connects several diaphragms along the culm's length, but in some internodes the rod disappear.

However, these characteristics are some time stable and some time unstable in their progenies. The segregation of the progenies often makes producers very uncertain. This is caused by the instability of the genetic factors, or the environmental conditions which play a leading role in the occurence of such diversifications which need convincing test data to be proven.

Therefore, no one is able to take the iniciative in production. In addition there are changeable genes in the vegetative plants which produce chimeras. This can be seen in the chimeras of various colors on the culms, branches and leaves of many bamboo species such as *Phyllostachys bambusoides f. tanakae* Makino, *Ph. glauca f. youzhu* Lu which have spots or strips of various colors on the culms, or on the culms, branches and leaves. Human beings often make use of these variations to breed new bamboo species of various ornamental values.

Many species of the genera *Phyllostachys, Bambusa,* etc. have many varieties or mutans which possess strips of various colors . For example the normal color of the culms, branches and leaves of *Ph. edulis* are green. *Ph. edulis f. luteosulcata* is a specie of gene mutation which has regular yellow strips on the concave site of the internodes. *Ph. edulis f. nabeshimana* has yellow and green strips on culms, branches and leaves. *Ph. aureosulcata, Ph. bambusoides, Ph. praecox, Ph. vivax, Bambusa glaucescens, B. vulgaris,*all have similar variations.

MATHEMATICAL RELATIONSHIPS OF THE CULM

Bamboo is the only plant which have a mathematical relationship between the circunference and the internode and the circumference and the length of the culm, which permits not only the identification of the species but also the determination of the culm height.

1.-Identification of bamboo species by mathematical relationship.

Dickason (1941) developed an interesting theory related to the identification of the species using as diagnosis the mathematical relationship which exists between the circunference or culm girth "C" taken at a height of 1.35 meters (4.5 feet) above the ground, and the length of the internode "L" located at this elevation (1.35 meters).

He gives the following relations C/L taken in some species: *Bambusa waming* Br. 1.4; *Dendrocalaus giganteus* Mun. 1.2; *Thyrsostachys siamensis* Gam. 0.94; *Bambusa vulgaris* Schrad. 0.92; *Bambusa vulgaris* var. *striata* Riv. 0.90; *Dendrocalamus membranaceus* Mun. 0.70. *Meloccanna bambusoides* Trin. 0.44; *Cephalostachyum pergracile* Mun.. 0.35 ; *Melocanna humilis Kurz* 0.17.

He sugested this height (1.35 mts)above the ground as a matter of convenience: it is easy to reach, it is usually not covered by persistent overlapping sheathes, does not require the cutting of the culm.

2.-Approximate mathematical determination of the culm's height

There is a mathematical relation between the culm height and the girth or circumference of the culm taken at the eye level, as is traditional in Japan; but it can be taken at the breast level (the difference between the girth at breast level and that at eye level is very small).

Most buyers of bamboo culms in Japan, multiply the culm girth at eye level by a constant = 60 to obtain the culm length, or they multiply the diameter by "pi" (3.1416) and then by 60. This procedure is applicable to the culms over 7 cm. in diameter. In Japan thi method has used as means to judging the quality of the culms. If the culm is longer or the same length as that determinated mathematically, the culm is of very hihgt quality. If it is smaller then it is very low quality and consequently has a lower cost.

The constant varies according to the species. In Colombia I cut about 60 culms of *Guadua angustifolia* for my experiments. With Prof. Jorge Escobar we took all the measurements of each culm in order to find the "constant" that we had to use in order to calculate approximately the height of a culm in this specie, and the result was 58.2.

For example, if the girth at breast level is 0.40 mts. the aproximately height of the culm will be 0.40 x 58.2 = 23.28 m. Using the diameter instead of the girth, the height will be: diameter x 3.1416 x 58.2.

Approximate dimensions of some giant bamboos of genus *Guadua* at the time of Columbus' arrival in the Americas in 1502 .

Using on the above mathematical relation which allows us to determine approximately the height of the culms of giant species of *Genus Guadua* using the girth or circumference of the culm, it is possible to calculate approximately the height of the giant culms of genus *Guadua*, which there were in the Americas at the arrival of Colubus, five hundred years ago. For this purpose we can take in account the information which exist about the dimensions of their circumferences at that time.

For example: in 1526, Oviedo, a Spanish historian, wrote in ancient Spanish, about the circunferences of bamboo species in Ecuador: "*But among all types of bamboo, there are some that are extremely large and the internodes are as big as a heavy man's thigh, and they are three palms or more in circumference*" (Patiño 1975). - The "palm" is an old Spanish measurement = 23 cm=9 inches. If the largest bamboo in Ecuador (*Guadua angustifolia*) had a circumference of 3 palms "or more." this means that the minimun circumference was of 3 palms = 0.69 m, which corresponds to a diameter of 0.22 m.Then the minimum high of this bamboo was 0.69 x 58.2 (constant) =40 meters. If we compare these dimensions with those that this specie has today: 0.10- 0.12 m in diameter by 18 to 21 m hight; this means that the dimensions of *Guadua angustifolia* have been reduced by 50% in almost 500 years.

In discussing to the dimensions of the internodes, Simon (1637) points out that "*The largest internodes have the capacity of one arroba of water*" The arroba is a Spanish liquid measure which is equal to 25 pounds= 11,500 gr.= 11,500 cm^3 of water capacity.

If the exterior diameter was 22 cms. the interior was about 18 cms.This means that the length of the internode was about 48-50 cms. Probably was taken of the center of the culm where are found the largest internodes.

Marco Polo said than on his trip to India in 1290, he saw very large bamboos with a diameter of 45 centimeters which were used as boats by the natives for going from one side to the other of the largest rivers.

Without doubt he was refering to the specie *Dendrocalamus giganteus*, the largest bamboo native to India. According to Prosea (1995), this bamboo today is 18-25 cms in diameter and 26- 30 meters height. This means that this specie also has reduced its dimensions by 50% in 710 years.

According to the above, the diameter and height of the bamboo culms in Asia and the Americas have been reduced little by little, probably due to continuous climatic changes in the world and to the destruction of the bamboo forests in the last 200 years.

The huge dimensions of giant bamboos in ancient China

Up until now I have been very sceptical about the information I had found in several ancient books from China about the extraordinary and incredible dimensions which some bamboos in that country had 3000 years ago. But keeping in mind the reduction of the dimensions of the culms of most of the giant species in the world, I think that this informations could be valid.

For example, according tothe book *Sheng iching* (*Records related to the marvelous things*) written by Tung Fang, who lived in the 2nd century B.C; in the southern wildernesses in China there was a bamboo known as *Ti chu* (Weeping bamboo) which grew to a height of several hundreds of chan (one chan= 10 feet=3,33 m; one Chinese foot or chi = 0.333 m). The circumference of this bamboo was 3 chan and 6 chi; and the culm thickness was eight or nine "tsun". (tsun =one inch). Its shoots are delicious and if they are eaten they will cure ulcers

If the dimensions have not changed since ancient times and if there is no mistake in the dimensions given by Hagerty (1919) in his translation of this book, this bamboo had a circunference of three "chan" antd six "chi"=36 Chinese feets =12 m, which corresponds to a diameter of 3.80 m., and the thickness of the wall would be about 20-22 cm.

The book *Chu Pu* written by Tai Kai Chi (265-306) says that "*in Yuang-chiu a bamboo known as Tin Chun Chu grows. This bamboo is so large that a boat can be made from each one of their internodes* ", this is confirmed also by Kuo Po of Erh ya.

The Treatrise on Agriculture (*Nung Cheng Chuan Shu*) compiled by Hsu Kuang-chi and originally published in 1640 says that the *P'ei chu* (Giant bamboo) is found in the southwestern part of the Han-shan district in Anhui pro-ince. According to the *Tz'u yuang,* this variety measures one-hundred "chan" (= 333 m in height), has a circumference of three "chan" and five or six chi (about 35 chi = 11.65 m = 3,70 m in diameter. The thickness of the culm wall is eight or nine 'tsun'. Its lumber can be used for building boats. Its seeds have a good flavor and, if they are eaten they will cure ulcers or sores.

The same Treatrise on Agriculture (1640), says that the *Lung kung chu* (Dragon duke bamboo) is a large variety that has a diameter of seven "chi" (1 chi= 0.333 m x 7 = 2.33 m in diameter) and between each joint (internode) there is a space of one "chan" (ten Chinese feet) and two "chi" (12 chi =0.333 x 12 = 4 m). The leaves of this variety are like those of the Chiao (banana) which grows in the Lo fou shan (range of mountains in the Kuangtung province).

In the book *Tu Shu Chi Cheng* there is information about two varieties from the Fan yu hsien district which have the same characteristics as the above species, but with different names, the " Dragon duke bamboo" is known as "King of Yueh bamboo" (Yueh wang chu) which has a culm so thick that it requires about four or five people with joined hands to encircle it. This variety of bamboo produces shoots in the fourth and fifth months, the volume of which are the size of a "tou" (tou=100 liters).

The opposite in dimensions is the " *Lung sun chu* (Dragon's grandson bamboo) which grows in Chen-chou (locality in Hunan) ussualy in the valleys and ravines. They are as fine and slender as a needle with a height that does not exceed 30 cm.

The influence of the culm age

The influence of the culm's age on its economic value is perhaps greater in bamboos than in any other timber. The age of the culm when cut has an important bearing on its use in the manufacture of industrial products and as material for construction.

Age is a very important factor for the development of certain strength properties. It is the general assumption that bamboo culms mature in about three years and have then reached their maximum strength.

According to Liese (1985), investigations with *Dendrocalamus strictus* have shown that in the green condition, older bamboo culms have higher strength properties than younger ones. According to my experiences with *Guadua angustifolia* the age of the culm increases only certain strength properties, such as compression strength and shearing stress, but in the case of tensil strength there is little difference between young bamboos one or two years with older ones.

In the experiments I did with bamboo strips taken from the external part of the culm wall, the maximum tensil strength was 3,217 kg/cm2 for culms 3.5 years old, and 3,206 kg/cm2 for culms one year and a half old. Probably this is the reason why the Chinese used bamboo strips one year old or less for the manufacture of bamboo cables which they use for the construction of suspension bridges with more than one hundred meters of span.

The durability of an individual culm varies according to the specie and the maximum is about 12 years at the end of which the culm dies and becomes dry and white.

According to my observations the strength of *Guadua angustifolia* starts decreasing in the grove when it is about 7 to 8 yeas old, consequently it is recommended that culms up to 6 years old be used in all the fields of construction.

Determination of the culm's age

Unlike trees, the diameter and height of a bamboo culm do not determine its age, but certain changes are generally recognizable as the culm becomes older. The only method for determining the age of bamboo culms accurately, is marking each culm shoot using an aluminum plate with a collar (nylon) located around the shoot with the year and date of its emergence.

In the second method, "visual factors" that are not very exact are used. In this method the one year old culms of many giant species of genus *Guadua* are easily recognizable by the emeral green color of the culm, and because they still have the lower sheaths partially fixed to the culm in its lower part.

The three years old culms can be recognized because the green color is not so dark and small white dots about 1-2 mm appear on the surface With the years these increase in diameter and become large lichens when the culms are 5 to 6 years old. One of the best methods consists in counting the leaf scars in the branches as is shown in the Fig. 1.16

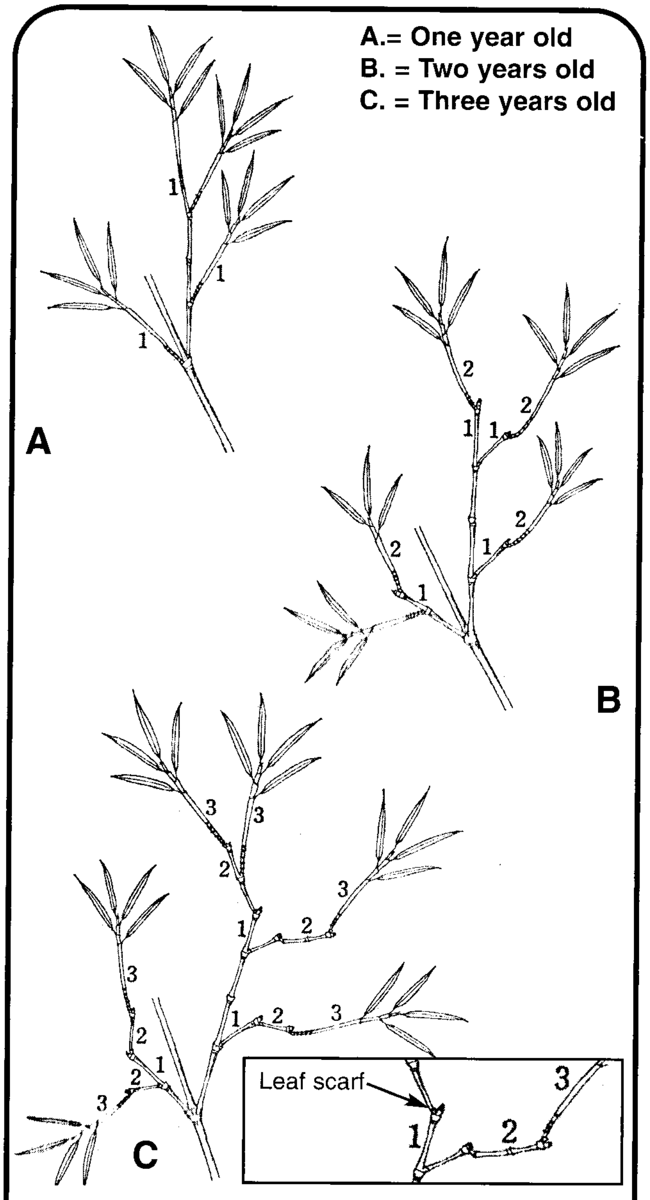


Fig. 1.16 *Determination of the culm age by number of leaves scarfs in the branches. The top branch (A)belongs to a bamboo one year old. The branches (B and C) belong to plants two and three years old respectively.*

CULM BRANCHES

Branchesare generated from the branch bud, or axillary meristem, which are arranged on alternate sides of the culm. Each internode bears a branch bud (primordium) located just above the culm leaf scar, and may be found from the lowermost node upwards as in *Guadua angustifolia,* or from the midculm node upwards. In some species branches develop while the culm is still growing, in others they develop only after the culm reaches its full height.

In some bamboos the branch bud is solitary. The branch system is often very characteristic of bamboo genus. If the apex of the culm is damaged, the dormant primary branch axis of each node will grow and elongate to replace the main culm. The array of branches may develop at a single culm node and is called a branch complement. In bamboos whose culms are branched, it is at the mid-culm nodes than the typical form of the branch complement appears.

The number of branches on each node of the mid-culms is important taxonomically and it differs with the genus. The branch complement appears most typically at the mid-culm nodes. The lowermost and uppermost branch complement are generally less well developed than those at the mid-culm nodes. In bamboo plants there is only one bud at each node in all genera.

About the branch primordium and its growth . In many bamboos the branch primordium ramifies precociously in the prophyll at the early stage. In *Sasa, Sasamorpha* and most *Sasaella*, the primordial branch axis possesses no basal buds and does not ramify, so the branch remains solitary. *Phyllostachys* typically ramifyes one time and is binary; the primary and secondary branches being unequal, some times a third much smaller one develops between the other two. The primary branch emerges, and remains strongly dominant. Subsequent orders of axes that develop from its basal buds gradually become smaller in size and shorter in length.

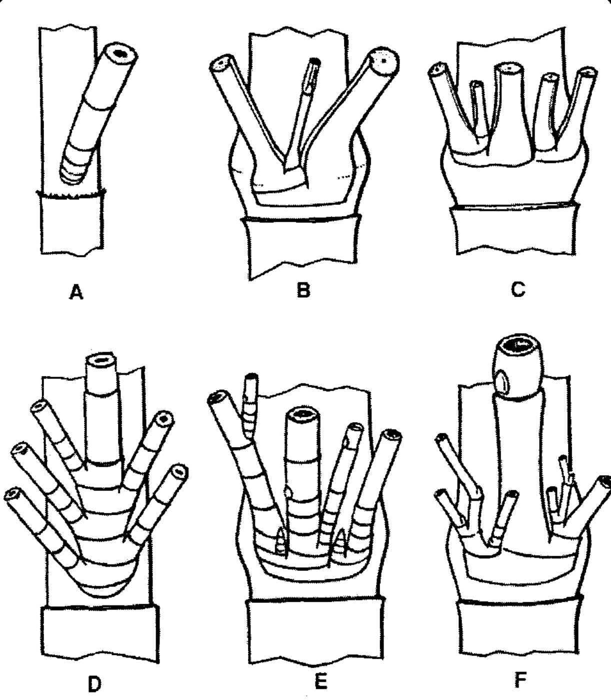


Fig.1.17 *Examples of diverse basal proliferation in the mid-culm branch complement in several genera: (A) Guadua angustifolia, (B) Phyllostachys dulcis, (C) Shi-bataea kuma-sasa, (D) Arundinaria tecta, (E) Arundinaria simonii, (F) Semiarundinaria fastuosa. McClure (1966).*

THE LEAVES

Probably the specie which have the largest leaves is *Neurolepis elata* from the Andes which may reach a length of 5 meters and a width of 0.50 m. While the smallest are those of *Arthrostylidium capillifolium* which are no wither than 3 mm.

According to Ueda (1987) , bamboo leaves fall off at one year after they appear and are renewd. Old leaves change into new leaves at the same time. Even the season and the way of renewal are different according to the species. The season for the species of large size bamboos is spring in general. This special ability for quick renewal is efficient for staying greeen and heightening the efficiency of photosynthesis.

That is because a bamboo ought to be strong in air polution. In general the small species also stay green by gradually changing old leaves for new ones as a unit of individual living bamboos.

In japan leaf change of new bamboos with pachymorph rhizome is finished in July. This is the period for vigorous growth of new leaves and is also the period for new rhizome growth. There is a close relationship between the leaf change and shoot sprouting. The number of sprouts is less in leaf changing year, but increases the next year.

Nonaka &Sasaki (1992), observed that in the damage of bamboo groves in Fukuoka, Japan, by a typhoon in 1991 leaves lost color and withered in a few days just after the typhoon but about ten days later new leaves appeared.

Uses.-Bamboo leaves are used for thatching houses and provide valuable fodder for cattle and for elephants in India. According to Kawase & Ujie (1987), in Japan, the leaves of miyakozasa, or tini *Sasa*, have been used as the feed for pastured horses since old times. Dried mature bamboo leaves are used for deodorising fish oils. At the same time, there has been the folklore belief that the extracts from the leaves are effective for the treatment of some cancers, and an infusion prepared from them has been drunk.

Since the cancer became a leading cause of mortallity in Japan, the medicinal effect of the extract from Sasa leaf (called Bamfolin) has been brought to the atention of the medical and farmaceutical fields. A lot of useful results are reported by the tests of animals receiving transplanted cancer cells. In relatively few clinical tests, Oshima treated 69 patients of seriously cancerous diseases with Bamfolin for over six months and reported that some curing effects were recognized by 10% of all patients, besides a promotion of appetite and an alleviation of pain. (See Pharmaceutical uses of leaves).

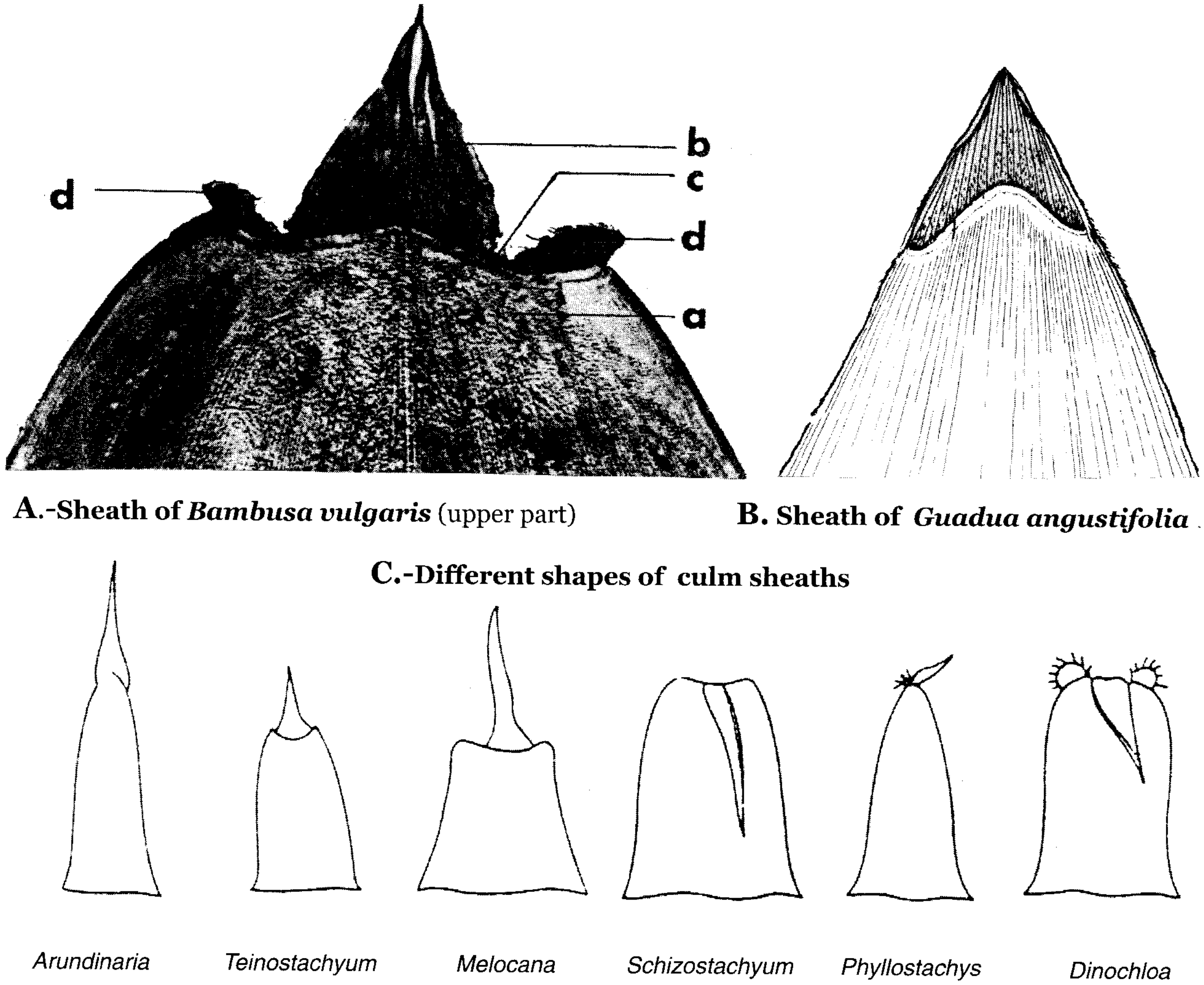


Fig. 1.18 Types of culm sheaths or culm leaves. *1.- Upper part of the sheath of Bambusa vulgaris showing one part of the structures that are important in classification and in identification of the different bamboo species: (**a**) Sheath proper, (**b**) Sheath blade, (**c**) Ligule, (**d**) Pair of auricles. **2.**-Upper part of the sheath of Guadua angustifolia in which it can be seen that the triangular border is continuous around the sheath. **3.**- Some different types of sheaths.*

Culm sheath (Culm leaf)

As was explained before, the growing of the bamboo culm takes place in the internodes. The upper part of each node consists of meristematic tissue, surrounded by the culm sheath, which has the function of protecting, supporting and stiffening the tender meristematic zone of the internodes of the culm and branches during their growing process. In the culm sheath there are many vascular bundles running longitudinally in almost parallel lines.

According to McClure (1966), when Chinese gardeners wish to dwarf a bamboo, they remove each culm sheath prematurely, beginning with the lowest, before the elongation taking place above its node is completed. Upon the removal of a sheath, the elongation above its node ceases.

The culm-sheath is an important structure for bamboo classification. The shape, size, thickness and hairiness of both the sheath proper and sheath blade and the existence of auricle or oral setae are invaluable for recognizing the genus or species. The inside face is smooth and shiny; when young the outside or the back is usually covered with irritant hairs which may be white, pale brown, golden brown or black. The sheath also varies in color and may be green, bluish or purplish-green, or yellow tinged with orange.

Culm sheaths generally shed the culm upon attaining maturity, but may also be persistent (*Sasa, Pleioblastus*), late desiduous (*Indocalamus Semiarundinaria, Fargesia* etc.) or early deciduous (*Bambusa, Phyllostachys, Dendrocalamus* etc.). In the external form, the sheaths of *Guadua* and *Chimonobambusa* are triangular, while those of *Dendrocalamus* and *Phyllostachys* are bell-shaped, and for *Schizostachyum* and *Lignania*,they are lanceolate. Sheath leaves of *Chimonobambusa* are short and small, and awl-shaped. (Keng and Wen, 1991).

Uses: Bamboo sheaths provide substitute material for lining hats and sandals, and used also for packing food.

ANATOMY OF THE BAMBOO CULM

The anatomical structure of the bamboo culm is the basis for understanding the physical and mechanical properties of the culm and its structural behavior.

As mentioned earlier, the bamboo culm is a tapered cylinder, generally hollow divided into segments or internodes separated by diaphragms (nodes) which, together with the hard, thick and cylindrical wall gives the culm great mechanical strength. While the culmss of most bamboos are hollow and erect, in others they are solid and either erect, scandent, or climbing and vinelike. Solid culms, known as "male bamboos" are found in the Americas in genera *Chusquea* , *Atractantha*.and *Otatea* from Mexico. In India are found in the specie *Dendrocalamus strictus*. According to Deogun (1936),this specie is solid when it grows on arid slopes, ridges and rocky soils, and hollow when it grows in the moisture valleys, and Sometimes some of the lowest internodes of a culm are solid but the rest of the culm is hollow.

Along the culm axis, the average internode length increases from the base to about the middle part, and then decreases to the top of the culm. In the internodes the cells are axially oriented whereas in the nodal diaphragm an intensive branching of the vessels provides transverse and radial conduction through the nodal diaphragm so that all parts of the culm are interwoven. Liese (1992).

The transversal section of an internode wall of a mature culm, shows the following typical anatomical structure:

1)- The epidermis, or outer most layer of the cortex. is formed by two epidermal cells layers with a high silica content which strenghtens the epidermal layer. The epidermal cells of the cortex are covered by a cutinized layer or glossy surface known as *cuticle* composed of cellulose and pectin with a wax coating on top. Beneath the epidermis lies the hipodermis , consisting of several layers of thick -walled sclerenchymatous cells (Liese, 1985).

2)-The inner layer of the culm wall in the interior or central cavity called *lacuna*, is composed of layers of parenchyma cells which are often thick and highly lignified and some times shows a suberized membrane which makes the chamber formed by the internodes impervious and airtigth. This thin membrane may be closely attached to the inner wall or loosely attached even in a one year old culms. This occurs in the first year in some species (*Phyllostachys viridiglaucescens, P. aurea*) and after three years in *P. heterocycla.*

According to Takenouchi (1939), In Japan, people used to call this membrane "bamboo paper". It is, of course, a dead and dry pith tissue, not a paper. This membrane was used in playing the Japanese flute by covering a finger hole with it to produce a characteristic sound.

The same author points out that the inner surface of the culm wall varies with the kind of bamboo. In some species like *Pseudosasa japonica* (Yadake) there are small scattered floccose particles resembling cotton which vary in form. They could be fairly large, arranged in cros-stripes or stepladder, while in others the surface is clean and smooth.

3)-The fibro-vascular area is located between the cortex and the inner layer of the culm. It consists of parenchyma cells as a ground tissue and vascular bundles composed of a conducting tissue (metaxylem vesells, sieve tubes with companion cells.) and fibres.According to Liese (1998), on an average, a culm consist of about 52% of parenchyma, 40% fibers and 8% of conducting tissue. These values vary with the species as can be see in Table 1-19

PARENCHYMA

The ground tissue of the fibrovascular area of the culm wall, consists of parenchyma cells which surrounds the vascular bundles. There are two types of parenchyma cells: vertically elongated cells (100 x 20 mm) and short cube-like ones interspersed between them. The vertically elongated parenchyma cells are characterized by thicker walls with a polylamellate structure. They already become lignified in the early stages of internodial development or shoot growth, but can still be alive in culms more than ten years old. The walls of the short parenchyma cells remain mostly non-lignified even in mature culms; these cells have denser cytoplasm and thinner walls and retain their cytoplasmatic activity for a long time. The function of these two different types of parenchyma cells is still unknown. (Parameswaran & Liese 1981.; Liese, 1995).

VASCULAR BUNDLES

When we cut the transverse section of a bamboo culm many brown dots can be observed in the wall. These dots at the out side and inside of the cross-section have different shapes. Each one of these dots is a vascular bundle. Enlarged photographs of the culm wall showing the vascular bundles can be seen in Fig. 1.19 and 1.20.

The gross anatomical structure of a transverse section of any culm internode is determined by the shape, size, arrangement and number of vascular bundles which are composed of both the mechanical tissue made up by *fibers,* and the *conducting tissue* which consists of two *metaxylem vessels, phloem*, a few *sieve tubes* with their *companion cells,* and *protoxylema,* which are the main arteries for the longitudinal movement of sap. The vessels transport water from the roots of the underground rhizome all the way to the upper leaves. The sieve tubes transport nutrient solution or assimilates from the leaves to the parenchyma cells in the rhizome and culm, and the protoxylem located between the two large metaxylem vessels, has the function of transporting water to the shoot in its early stages of growth. Because of the length of the bamboo culm the conducting tissue is reinforced by an outside mechanical tissue which embrace the conducting tissue and protect it when the culm is bent by the wind. The vascular bundles are surrounded by the parenchyma ground tissue.

According to Taihui and Wenwei (1985) the parenchyma in the vascular bundles serves as a buffer zone contributing to the elasticity of the culms, without which the culms would be inflexible and brittle.

The thickness of culmwall decreases from base to the top due to the reducction of its inner portion containing more parenchyma and fewer vascular bundles.

A

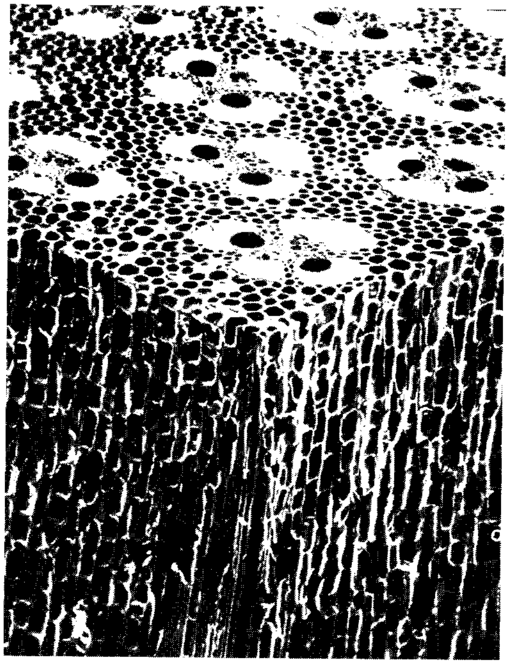
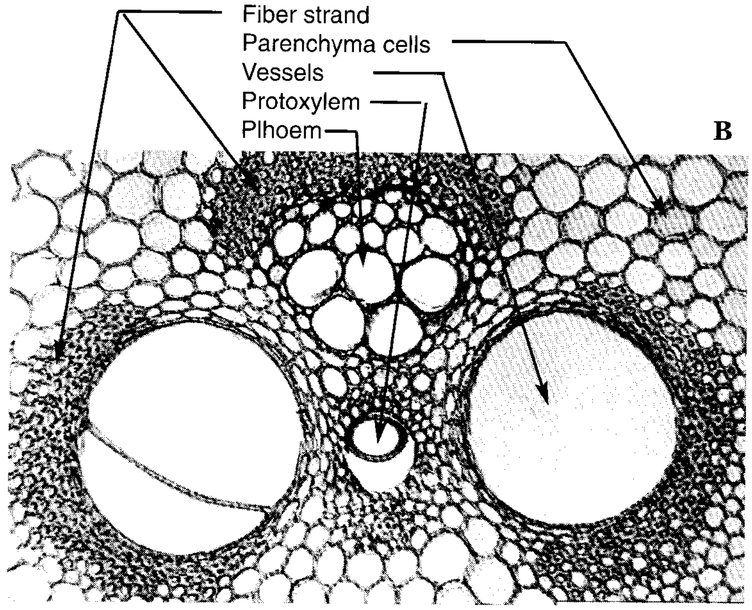
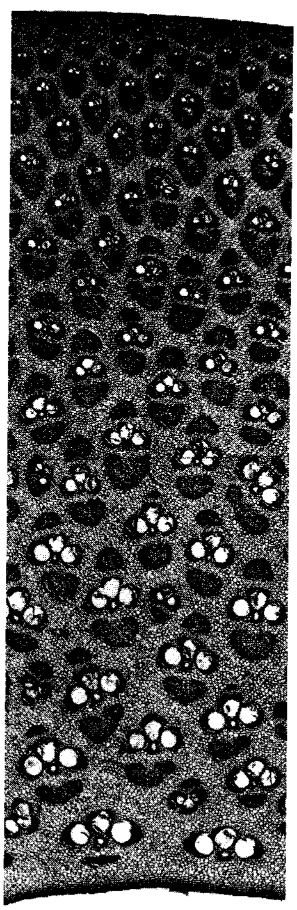


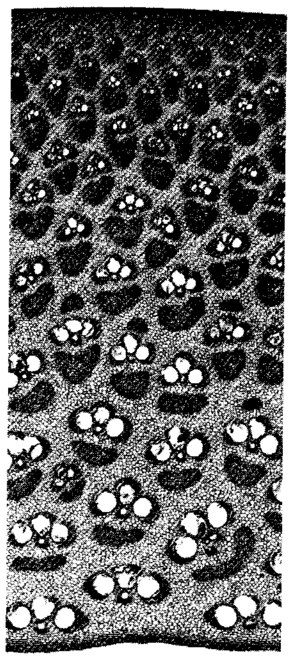
Fig. 1.19 THE VASCULAR BUNDLES



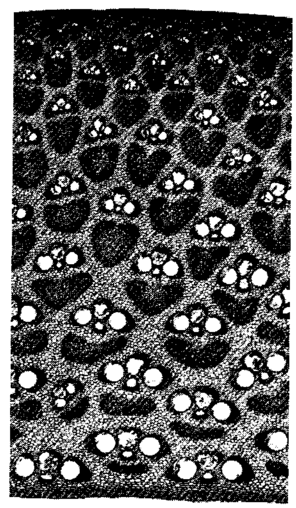
A- *Three- dimensional view of a transversal section of a culm wall, showing part of the fibro-vascular area with several vascular bundles surrounded by parenchyma (courtesiy of W. Liese).*

B *Vascular bundle with two large metaxylemvessels (4))and phloem (3) surrounded by fibers (1). (Courtesy of W. Liese).*

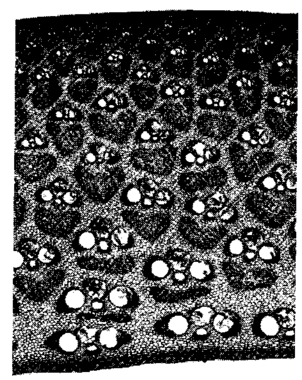




10 th internode



14 th internode



18 th internode

6 th internode

C.- *Changes in the vascular bundle structure at the 6th, 10th. 14th and 18th internodes along the culm height in Oxytenanthera nigrociliata.)Courtesy of Walter Liese.).*

The upper part of the culm with more vascular bundles and less parenchyma, has a higher specific gravity and therefore bending and compression strengths increase with height. Only the fibre length exhibits a slight decrease in the top part. Liese (1995). Liese Weiner (1996).

The total number of vascular bundles in the culm wall decreases from outer to inner parts and from the bottom to top. At the peripheral zone of the culm, the vascular bundles are smaller and numerous, at the inner part of the culm they are larger and fewer, and reach its maximum dimension at the innermost part of the culm wall.

The vascular bundles immediately below the cortex are circular in transverse section. Towards the midle of the culm wall, the vascular bundles become larger and more widely spaced. In most species, they exhibit their maximum size and characteristic form in the central part. In the inner culm part, the vascular bundles again became smaller. (Liese 1998). To characterize the two-dimesional variation of vascular bundles in different internodes within a culm, Grosser (1971) developed vascular bundles patterns or diagrams for several species in which bundle shape and frequency are given in horizontal rows for succesive internodes. Fig. 1.20.

The density of vascular bundles or number of vascular bundles ocurring in one square millimiter varies from the epidermal layer toward the pith peripheral layer and according to the species. In the study conducted in Taiwan by Wu & Wang (1976) on the density of vascular bundles, at the middle part of the culm wall, they found one vascular bundle by square millimeter in *Dendrocalamus latiflorus* and about 3-4 for *Phyllostachys pubescens* var. *pubescens.*

Wu & Hsieh (1991) found in *Dendrocalamus latiflorus* and *Phyllostachys pubescens* var. *pubescens* at the first millimeter inside the epidermal layer, there are significantly high densities of vascular bundles with 8-10 for the former and 7-8 for the the latter. The density decreases at the second milimeter, 2.5-3.5 for the former and 3.5-4.5 for the latter. Espiloy (1985) reported that the density of vascular bundle at the top of the culm is larger than that at the base. Along the axis of the culm of *Bambusa blumeana,* she found 3.80 for the top and 1.74 by square millimeter at the base.

The vessels. The diameter of vessels increases from the epidermal layer to the inner pith cavity of the culm wall. Wu & Hsien reported that in *Dendrocalamus latiflorus* the average diameter in the 6th, 14 th and 22th internodes are 18.8 μm, 15.0 μm and 15.2 μm respectively at the outer part of the culm wall. The average diameter increases to 164.6 μm , 151.4 μm and 132.0 μm at the middle part of the culm wall and increases further to 205.0 μm , 202.4 μm, and 176.4 μm at the inner part of the culm wall.

In *Phyllostachys pubescens* var. *pubescens* the variation of vessel diameter increases from the base to the top of the culm. Espiloy (1985) found that the average diameter of vessels of *Bambusa blumeana* is 186.3 μm at the base internode, decreases to 136.6 μm toward the middle part and increases to 173.6 μm at the top.

According to Liese (1998) The vessel area at the inner half of the culm generally amounts to double that at the outer half. The area and size of metaxilem vessels in transverse sectionare very important for determining the conductivity of water in the living plant, and also for the preservative treatment of fresh culms by the sap displacement method, since the vessel area is a decisive factor for calculate the treatment parameters.

A detailed analisis of the bundle types and their variations was undertaken by Grosser (1971) and Grosser and Liese (1971,1 973) for 52 species in 14 genera. They analyzed the variability of vascular bundles in form and size, and grouped them into four basic types. There are a considerably variability in the appearance in the vascular bundles within one culm, both across the culm wall and longitudinally along the culm for simpodial bamboos. Further investigations on other species have contributed additional information. (Liese 1998).

Fig. 1.20 Anatomical characterization of the vascular bundles of *Phyllostachys edulis* Riv. in six internodes *(Groser 1971; Lieese 1998)*

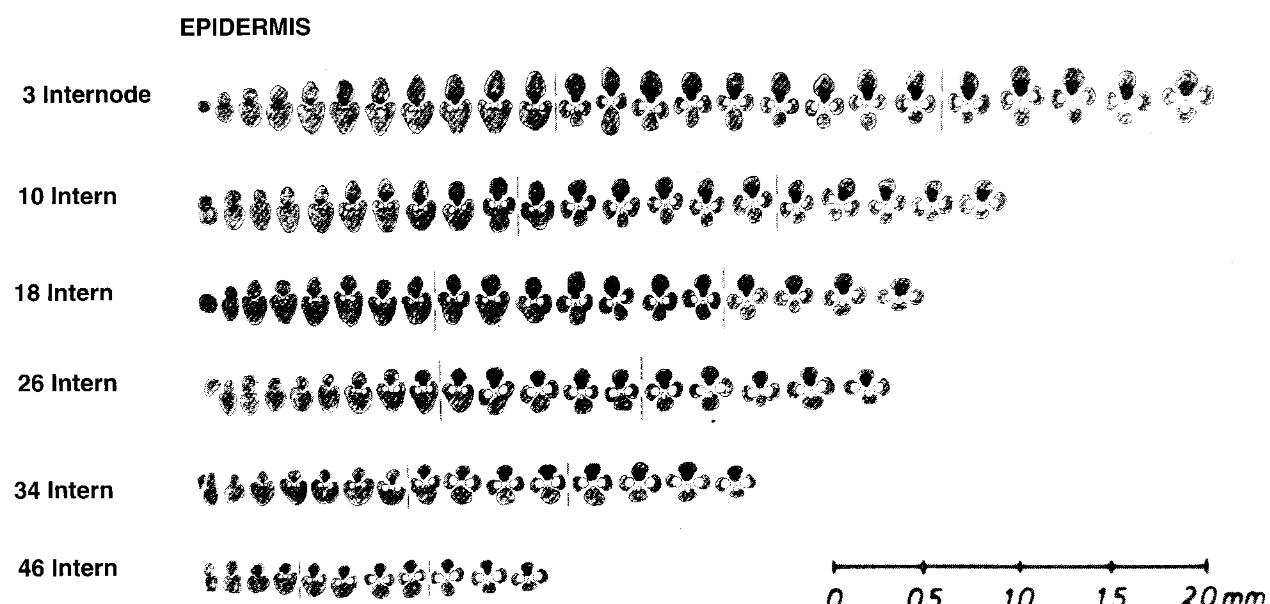
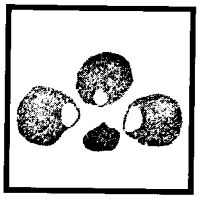
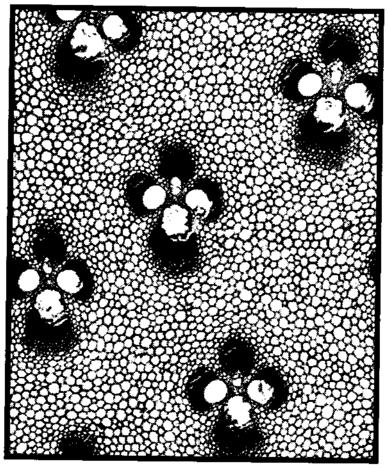


Fig. 1.21 TYPES OF VASCULAR BUNDLES

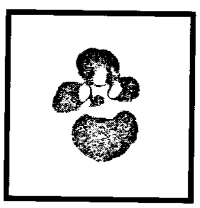


Type I

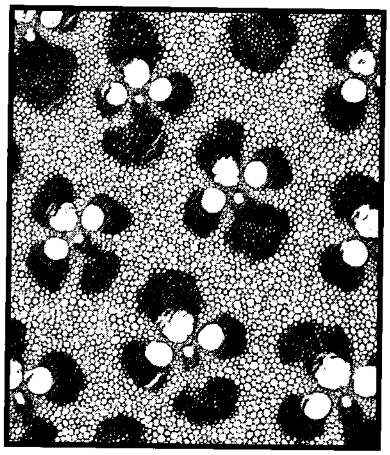


Vascular bundle Type I -(Open type)

This type onsists of one central vascular strand with supporting tissue only as sclerenchyma sheaths. The vascular bundles sheaths are of the same size and symmetrically located. Most of the bamboo species which possess this type of vascular bundle sheath are of monopodial and amphipodial types. Examples are the genera *Arundinaria, Phyllostachys, Pleioblastus, Shibataea, Bashania, Brachystachyum, Cephalostachyum, Chimonobambusa, Chimonocalamus, Neomicrocalamus, Pseudosasa, Indosasa, Qiongzhueea, Acidosasa, Oligostachyum,* and *Sinobambusa.*

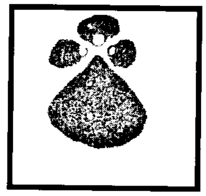


Type II

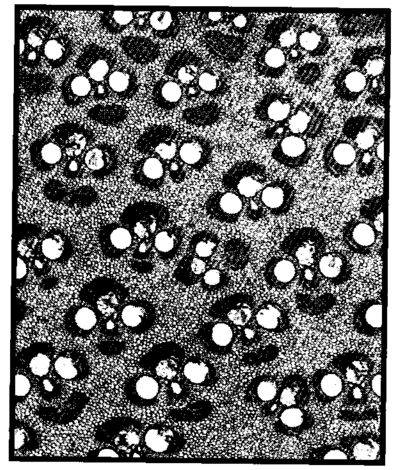


Vascular bundle Type II (Tight-waist)

This type consists of one central vascular strand with supporting tissue only as sclerenchyma sheaths. The sheath at the intercellular space (protoxylem) is strikingly larger than the other three and extends in a fan-like shape. Bamboo species which possess this type of vascular bundle are pachymorph type (sympodial). Examples are the genera *Schizostachyum, Melocana* as well as some individual species of *Cephallostachyum.*



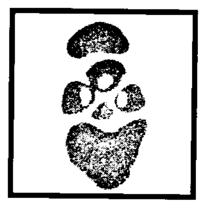
Type III



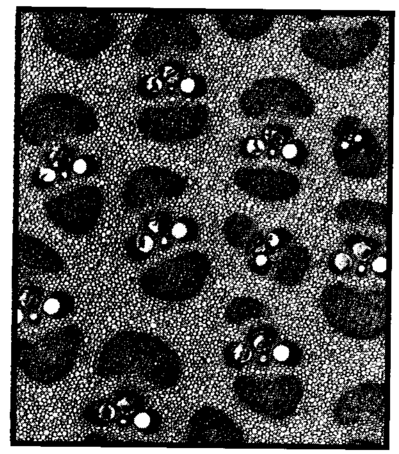
Vascular bundle type III (Broken waist)

This type consists of two parts, the central vascular strand with sclerenchyma sheaths and one isolated fiber bundle. The sheath of the inner vascular bundle between the cells (protoxylem) is usually smaller than the other vascular bundle sheaths. Bamboo species of this type all belong to pachymorph type (sympodial).

Examples are genera *Bambusa, Ampelocalamus, Dendrocalamopsis, Dendrocalamus, Melocalamus, Pseudostachyum, Gigantochloa*, as well as some species of *Schizostachyum.*



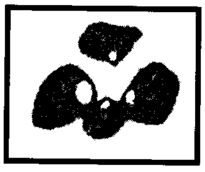
Type IV



Vascular bundle Type IV (Double-broken)

This type consists of three parts, the central vascular strand with small sclerenchyma sheaths and two isolated fibres bundles outside and inside the central strand. Bamboo species of this type are all pachymorph type (sympodial) and grow into dense clump.Examples are the genera *Thyrsostachys, Gigantochloa, Dinochloa, Dendrocalamopsis, Dendrocalamus* as well as some species of *Bambusa and Neosinocalamus.*

After Grosser and Liese (1971,1 973)



Type V.

-In 1992 Ya & Xu added the type V that they called Vascular bundle type V (semi-open) There is no fiber sheath, but the lateral and inner vascular bundle sheaths are linked together. Bamboo species of this type are the genera *Sasa, Sasamorpha, Yushania, Fargesia,* as well as some individual species of *Qiongzhuea and Indosasa.*

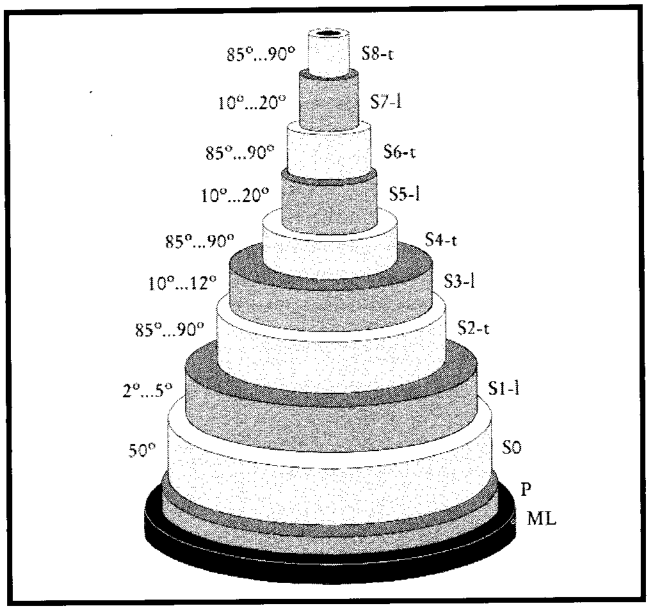


Fig. 1.22 *Model of polylamellate structure of thick-walled bamboo fiber Figures on the left indicate the fibril angle. (Courtesy of W. Liese. 1998).*

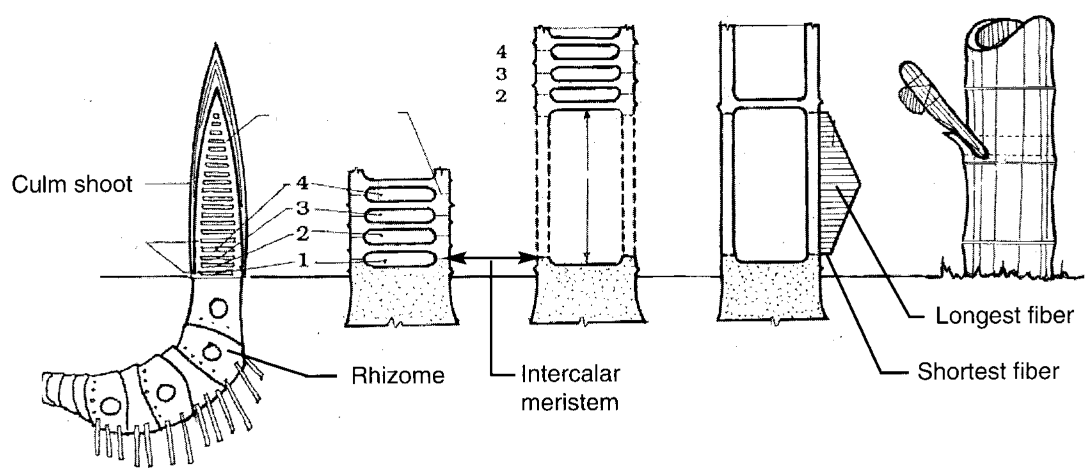
Fig.1.23 *Polylamellate structure of a parenchyma cell wall, Phyllostachys pubescens (Syn. Ph. edulis) 19/000 X. (Courtesiy of W.Liese. 1998).*

FIBERS

Fibers are the mechanical tissue and their function is essentially to impart strength to the culm. They constitute 40-50% of the total tissue. They occur in the internodes at the vascular bundles as fiber caps (sclerenquima sheaths) surrounding the conducting elements and in some species additionally found as isolated strands. At the periphery of the culm near the epidermis, there are generally one or two layers of fibre strands closely arranged giving mechanical strength.

The ultrastructure of most of the fibers is characterized by thick, polylamellate secondary walls. This lamellation consists of alternating broad and narrow layers with differing fibrillar orientation. In the broad lamellae the fibrils are oriented at a small angle to the fibre axis, whereas the narrow ones mostly show a transverse orientation.(See Fig. 1.22) The narrow lamellae exhibit a higher lignin content than the broader ones. This polylamellate wall structure is present especially in fibres at the periphery of the culm and their significance for bending properties appears obvious. (Parameswaran & Liese 1981); Liese 1976, 1995, 1998).

Fig. 1.24 Relationship between the fiber lengths in the internode



The shortest fibers are always located near the nodes and the longest are to be found in the middle part of the internodes. This means that the strongest and weakest part of the internode are located respectively in the center and the nodes. This made possible that the the first civilizations could cut the bamboo with stone axes (See Homo erectus), cutting the culm It two cm above the node, where the intercalary meristem starts and the grow of the internode finishes.

Table 1-1 The average fiber dimensions of some bamboo species.

Specie	Length mm	Width µm
Arundinaria alpina	2.30	23.0
Bambusa arundinacea	1.73	22.0
B.longispiculata	2.31	13.5
B. multiplex	2.20	14.0
B. tulda	1.45	24.0
B. vulgaris	2.64	10.0
Dendrocalamus strictus	2.23	22.0
Guadua angustifolia	1.60	11.0
Oxytenanthera abyssinica	1.51	12.0
Phyllostachys bambusoides	2.15	15.0
P.edulis	1.56	13.0
P. nigra	1.04	10.0
P. reticulata	1.56	13.0
Pseudosasa japonica	1.34	18.0
Sinocalamus latiflorus	2.88	14.0
Thyrsostachys siamensis	1.81	10.0

Source: Liese and Grosser (1972) Liese (1998)

Fibers contribute 60-70% of the weight of the total culm tissue. They are long and tapered at their ends. The ratio of length to width varies between 150:1 and 250:1. The fiber length shows considerable variation both between species and withing individual species. Across the culm wall the fiber length often increases from the periphery towards the middle of the wall and decreases towards the inner part. In the inner zone fibres are 20-40 % shorter. A greater variation in fiber length exists longitudinally within one internode. The shortest fibres are allways near the nodes, the longest fibres are in the midle part of the internode. This variation could be within one internode of up to 100% or more.

According to Wu and Hsieh (1991),the fiber length at the lower node of the second internode above the ground of *Dendrocalamus latiflorus* is 1.52 mm and 1.40 mm for *Phyllostachys pubescens* var. *pubescens*. The upper node of the same internode are 1.385 mm and 1.25 mm.

In the middle part of the internode the maximum fibre length reaches 2.49 mm and 1.98 mm respectively. The variation showed that the shorter fibers occurred about 2-3 centimeters near the node.Vertically, the fiber length increased from the basal part to the middle and decreased at the top (3.17-3.27-2.78 mm).These means that the fibers in the middle part of culm are the longest, next are those in the lower part, and those on the top are the shortest.

Generally, the bamboo fibers are much longer than those from hardwoods, but shorter than those of softwoods. Their length increases from the periferal layer inwards to a maximum in the outer third of the culm wall and decreasing again towards the inner wall. Different values have been reported within the same species. This is mainly due to the considerable variation of fibre length within one culm.

According to Liese (1990)the fiber length-to-width ratio varies across the culm from 70:1 to 150:1 (which is considered as suitable for pulping). As fiber length is an important pulping property, any measurement has to consider the pattern of variation within the culm by taking representative samples. The fiber length positively and strongly correlated with fiber diameter, cell wall thickness and internode diameter.

The fiber diameter varies from 10 to 40 µm, the lumen diameter from 2 to 20 µm and the cell wall thickness from 4-10 µm.The Runkel ratio (2Xwall thickness: lumen diameter) ranges from 1 to 4.. These values are influenced by fibre maturation, which leads to an increase in wall thickness. Immature culms are some times investigated for their pulping quality. But their small fibers wall thickness gives a lower Runkel ratio that makes them unsuitable for pulping. Bamboo fibres have hight tearing resistance, but low tensil strength based on their slenderless ratio and flexibility coefficient (Widjaja and Risyand 1987; Latif 1995).

Ma (1993) reported that the fiber lengths in culms of 26 different species are: 1.33-2.22 mm, averaging 1.89 mm; the width of fibers arc 10.8- 18.7 mm, averaging 16.1 mm. The ratio of length and width is 87-153, averaging 121. The ratio of fiber length and width of different parts is the same.

Certain species generally have shorter fibers, such as *Phyllostachys edulis* (1.5 mm), *Ph . pubescens* (1.3 mm.), other longer ones like *Dendrocalamus giganteous* (3.2 mm), *Oxytenanthera nigrocilliata* (3.6 mm.) *Dendrocala mus membranaceous* (4.3 mm) have longer ones.

Table 1-2 Percentage of cell types in bamboo species

Species	Parenchyma	Fibers	Conducting Tissue
Bambusa polymorpha	48	44	8
Bambusa tulda	47	45	8
Cephalostachyum pergracile	52	40	8
Dendrocalamus hamiltonii	51	41	8
Dendrocalamus strictus	50	43	7
Melocanna bambusoides	43	50	7
Oxitenanthera nigrociliata	51	43	6
Phyllostachys edulis	54	38	8
Phyllostachys machinoi	55	37	8
Schizostachyum brachycladum	54	38	8
Teinostachyum dullooa	52	40	8

Source: Liese (1998).

The fiber length influences density and strength properties and it is closely related to elastic bending stress. So far fiber length is hardly considered when selecting a bamboo species for a given purpose, except pulping, but from practical experience such relationships may already be utilized (Liese 1992).

The Tables 1-1 and 1-2 are very important for manufacturers of paper, composite materials and for builders because the length of the fiber influences the pulping properties and the strength of the culm. On the other hand the most strongest bamboos have height percentage of fibers and the lowest percentage of parenchyma.