# General Morphology, Growing Conditions and Development of Fiber Filaments in Lechuguilla (*Agave lecheguilla* Torr.)[1]

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## ABSTRACT

**Lechuguilla (*Agave lechequilla* Torr.) varies in morphological types and abundance under different edaphic conditions. Fiber cells in lechuguilla develop at the base of the developing leaf from procambial cells surrounding an undifferentiated mesophyll. Gradually these procambial cells develop into fiber cells and are transformed into fiber bundles with xylem and phloem on the concave side of the bundle. The sequential processes of the development of fiber cells and fiber bundles are discussed. The fiber bundles are youngest at the leaf base and highly matured at the leaf apex.**


**Key words : Lechuguilla, morphology, meristem, anatomy, fiber cells, fiber bundles, growth of fiber filament, quality.**


## COMPENDIO

**Se determinó la influencia de diferentes condiciones edáficas sobre la abundancia y tipos morfológicos de lechuguilla (*Agave lechequilla* Torr.). Las fibras celulares de la lechuguilla se forman en la base de las hojas en desarrollo a partir de las células procambiales que rodean el mesófilo indiferenciado. Estas células procambiales se forman gradualmente en células de fibras y se convierten en un manojo de fibras con xilema y floema en su lado cóncavo. Se discute la secuencia de los procesos en el desarrollo de las células de fibra y de los manojos, los que son menos maduros en la base de la hoja y más maduros en el ápice.**


## INTRODUCTION

Plant fibers have been used since the beginning of civilization and are obtained from different plant organs, including stems, leaves, seeds or fruits (9). They vary in their mode of development, structure, yield and quality (1, 5, 6, 8, 9, 10). Yucca (*Yucca carnerosana*) and lechuguilla (*Agave lechegui-lla*) are important commercial fibers and are significant natural resources in the arid regions of Mexico (11, 13). These two species play an important role in the economy of some rural people (11).

1 Received for publication 22 January 1991.
The authors thank the Centro de Investigación, Facultad de Agronomía, Universidad Autónoma de Nuevo León for the facilities afforded for this study, and Fernando Jiménez Guzmán, Facultad de Ciencias Biológicas, for his help in taking the microphotographs. Thanks are also due to Dr. Paul R. Earl for revising the manuscript.

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Owing to its high bending modulus, resiliency and springiness, lechuguilla fiber is in great demand in many countries for mass production of machine scrubbing brushes (3, 4). Maiti (7) reported that some species of *Agave* (*A. sisalana* and *A. cantala*) could be substituted for *A. lecheguilla* in its utilization in machine scrubbing brushes, provided the fibers are treated with resin. The anatomy of the fiber filaments can be correlated with the quality of the fiber (7, 8, 9). Significant differences were found in morpho-anatomical structures and yield components in *A. lecheguilla* among different localities, and many of the morphological and yield components were well correlated (6, 13). A regression model was able to be formulated for the prediction of fiber yield as a function of different morphological and anatomical variables.

Datta (1) reported that fiber cells in *A. americana* develop from the protophloem as well as from the ground tissue. The present study seeks to explain the general morphology, the developmental anatomy of fiber in *A. lecheguilla*, and to correlate growing conditions and fiber quality.

## MATERIALS AND METHODS

Three kinds of leaves were collected for the study of the development of fiber bundles: 1) very young leaves from the central cone, or "cogollo"; 2) partially developed leaves from the middle whorls; and 3) fully mature leaves from the external whorl of the plant.

Transverse sections were made from the three types of leaves at the base, middle and tip with a freezing microtome at 50/µm. For observation, each 50/µm (Alt 230) fresh section was put in 70% alcohol, then transferred to distilled water and mounted on a slide with a drop of glycerine and a drop of safranin (2% in water) with a cover slip.

The fiber filaments were extracted from the basal, middle and tip portions of the developing and mature leaves and then macerated with 10% nitric and 10% chromic acid (1:1) in a test tube at 60°C (2). From four to 24 hours were required for maceration, depending on maturity of the fiber filaments. The macerated fiber filaments from the base, middle and top portions were washed with water, and a fragment of fiber filament was mounted on a slide in 50% glycerine and stained with a drop of safranin or eosin. The development of fiber cells was also studied from serial longitudinal sections.

The fibers were extracted by scraping off the parenchymatous mesophyll tissue with a knife and drying it in an incubator at 60°C for three days. The tension and elongation of fiber strands of five large fiber filaments (obtained from the three regions of the leaf) and five short fiber filaments (from the peripheral regions of each leaf) were measured with a dynamometer (Woodbrand and Co. Ltd., U.S.A.). Fiber quality tests were measured only from the middle portions of each fiber filament.

## RESULTS

### General morphology and growing condition

*A. lecheguilla* is a monocarpic plant with a crown of basal leaves at the soil surface emerging from a central cone ("cogollo"). The leaves are lanceolate, tough in texture, and very fibrous, with a bluish or light green leaf surface and marginal curved spines (Fig. 1). The flowers are pedicellate borne in a long inflorescence (Fig. 2).

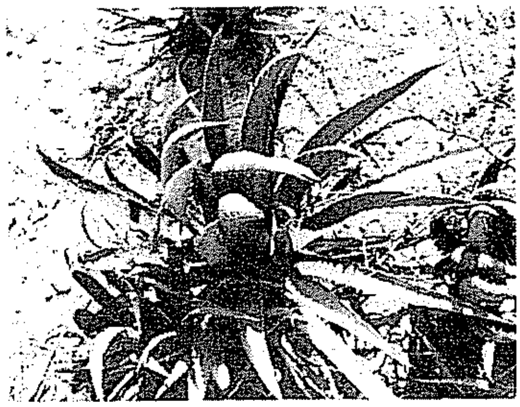

Fig. 1. *A. lecheguilla*, plant with a rosette of basal leaves having marginal spines and central leafy cone; "cogollo" (x 1/3 approx.).

Fig. 2. *A. lecheguilla* flowers with fleshy peduncle, leafy perianth and pendant versatile anthers (x 2 approx.)

Lechuguilla shows great variability in plant density and morphology under different edaphic conditions and degree of surface inclination in the arid regions of Nuevo Leon. It grows in rocky soils, with population density decreasing with a decrease in pebbles. Morphological types vary in leaf orientations, leaf forms, leaf dimensions, marginal spines and pigmentation.

### Developmental anatomy of the fiber bundle

The developmental stages of the fiber strands can be observed from the transverse sections of the developing and mature leaves at three different positions:

base, middle and top of central whorl, and also at the middle whorl and in the peripheral leaves (Figs. 3-14). A transverse section at the actively growing meristematic leaf base of the "cogollo" indicated that the procambial cells first form an incomplete circle of cells with accumulation of dense protoplasm, followed by a complete circle surrounding undifferentiated tissue in the center (Fig. 3). Gradually this takes on a crescent shape with the development of the vascular bundle on the concave side. The inner thin-walled tissue was gradually transformed into fiber cells starting from the concave and progressing to the convex side of crescent (Fig. 3).

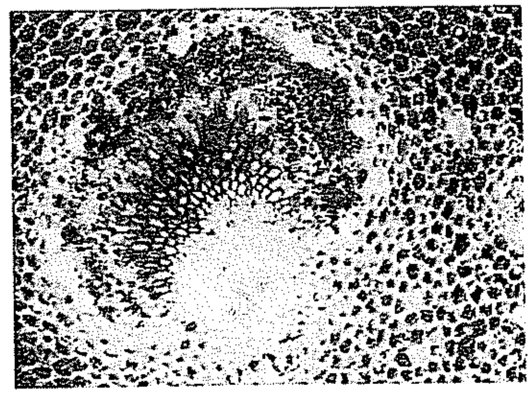

Fig. 4. Transverse section at the base of young leaf showing gradual transformations of thin-walled parechymatous tissue into a partially lignified fiber bundle (x 600).

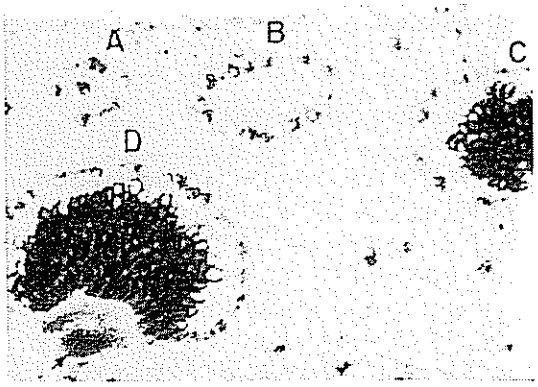


Fig. 3. Transverse section at the base of young leaf from "cogollo" showing (a and b) circles of procambial cells encircling undefined central tissue and (c and d) showing gradual development of fiber cells from the inner convex side of the semilunar fiber bundle x 150.

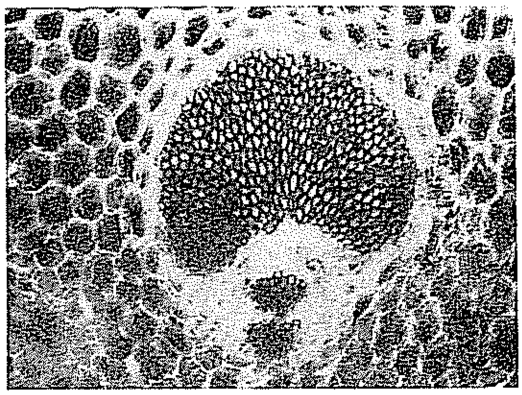

Fig. 5. Transverse section of the young leaf at midregion showing uniform partial lignification of developing fiber cells with broad lumen (x 600).

In a transverse section of the leaf at the base, middle and top portions of the three types of leaves, the fiber cells in the fiber bundles showed a gradual increase in degree of lignification with a broad lumen (Fig. 4), but the middle and apex of the same leaf showed higher degrees of lignification with a narrower lumen (Figs. 5 and 6). Subsequently, the maturing fiber cells in the bundle showed a greater degree of lignification at different positions in the middle and peripheral leaf whorls (Figs. 7 and 8). The fiber cells at the base of the mature leaf of the peripheral whorl were highly lignified (Fig. 9) compared with the same region of younger leaves (Fig. 4).

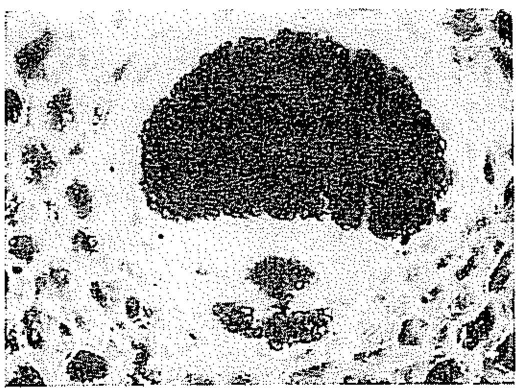

Fig. 6. Transverse section of the young leaf at the apex showing marked lignification of fiber cells and a narrow lumen in the differentiated fiber bundle (x 600).

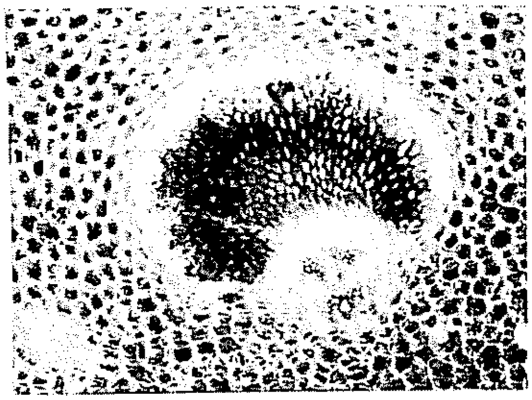

Fig. 7. Transverse section at the base of a partially developed leaf from the middle whorl showing gradual lignification of well- developed fiber cells in the bundle (x 600).

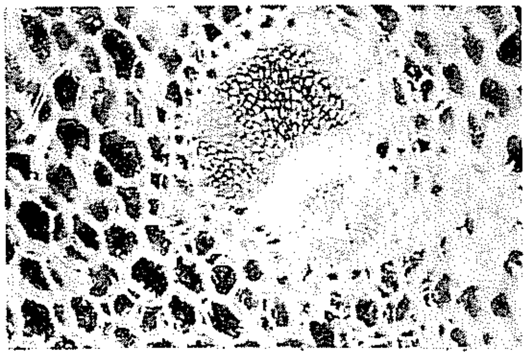

Fig. 8. Transverse section at the midleaf region of the partially developed leaf in the second whorl showing further development of bundle (x 600).

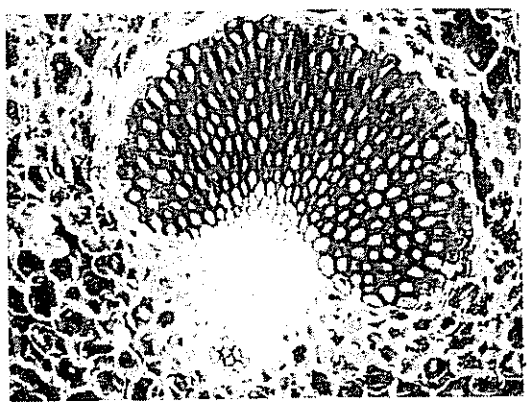

Fig. 9. Transverse section at the base of a mature external leaf showing lignified fiber cells with a broad lumen (x 600).

Owing to the extreme degree of lignification, it was not possible to section the apical spine of the mature leaf. The fiber bundles are at a much younger stage of development in the leaves of the "cogollo" compared with the middle and external leaves, which are highly lignified. Consequently, the fiber strands of the leaf base extend and converge gradually along the growing leaf through mesophyll tissue until they finally unite in the leaf apex to form the strong spine in all the leaves. The filaments at the margin of the leaf are short and do not reach the apex. The initiation of the fiber bundle was associated with the initiation of protophloem and protoxylem in the concave region of fiber bundle.

Subsequently, the development of the fiber bundle was closely associated with the development of the vascular bundle growing from the base to the apex. The highly developed vascular bundle showed organized phloem and xylem having a sheath at the concave side of the large fiber bundle. Differentiation of fibers occurs at two points: one in the protophloem and another in the abaxial xylem.

### Development of fiber cells

The fiber initials were developed in the meristem at the leaf base as a result of procambial cell formation associated with denser cytoplasm compared with the surrounding cells. Once formed, the developing fiber initials gradually elongate vertically from the meristematic base with thickening of secondary cell walls along the growing leaves. The lumen showed accumulated granular protoplasm with depositions in the primary cell wall (Fig. 10). Subsequently, the secondary wall thickens into a spiral reticulate pattern (Figs. 11 and 12).

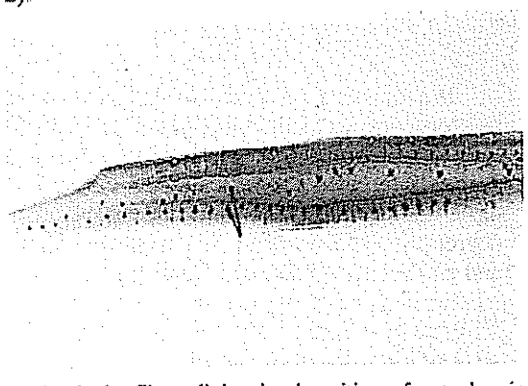

Fig. 10. A developing fiber cell showing depositions of protoplasmic contents on the primary wall in the form of small patches leaving pore spaces in between and accumulation of protoplasmic granules (arrow) (x 1000).

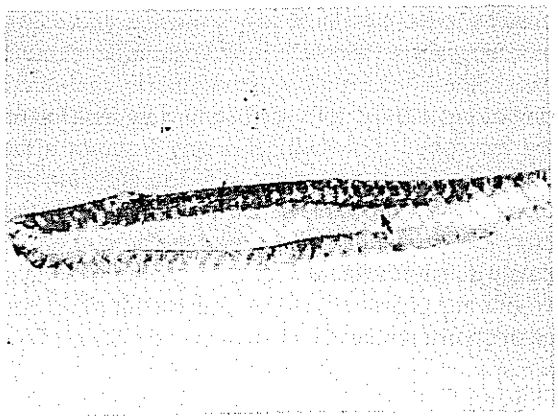

Fig. 11. A developing fiber cell showing accumulation of protoplasmic contents in spiral and reticulate manner (arrow to secondary fiber cell wall) (x 100)

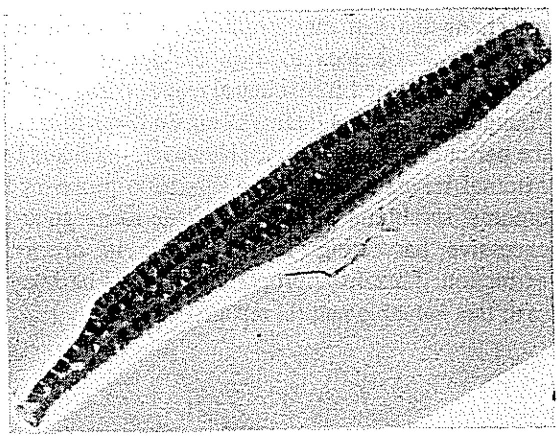

Fig. 12 A contrasting view of a developing fiber cell wall showing protoplasmic granules and depositions of secondary cell wall material in a spiral (x 100)

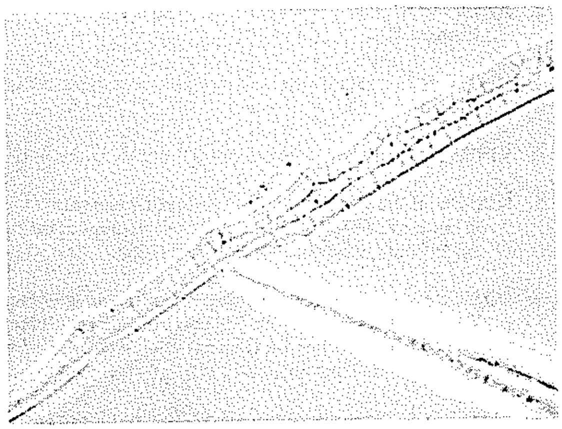

Fig. 13. Fiber cell in the middle part of a young leaf showing broad lumen and irregular constrictions (x 100).

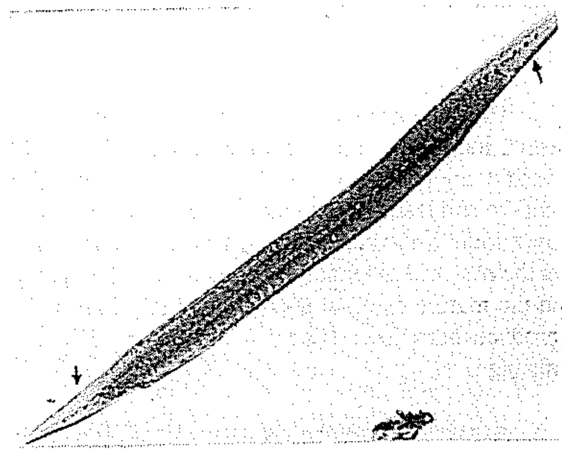

Fig. 14. A maturing fiber cell showing depositions on primary cell wall in small bands leaving pore spaces in between and presence of granules to form the secondary cell wall (x 1000).

The fiber cells in the middle of a leaf have a broad lumen with irregular constrictions (Fig. 13). Sometimes the lumen is narrow with a highly lignified secondary cell wall in the mature leaf (Fig. 14), but with maturation, the cytoplasmic granules disappear from the lumen.

### Tension and elongation of fiber filament

The results of the analysis of the physical properties of long central fibers and the short marginal fiber from three types of leaves are shown in Table 1.

**Table 1. Physical properties of fiber filaments from three types of leaves (mature, partly developed and young) (average of five filaments).**

| Leaf type | Long fiber filament | | Short fiber filament | |
|---|---|---|---|---|
| | Tension (cm) | Elongation (cm) | Tension (cm) | Elongation (cm) |
| Young | 2.840 | 3.42 | 1.070 | 1.52 |
| Partly developed | 3.090 | 3.54 | 945 | 1.50 |
| Mature | 2.075 | 1.56 | 799 | 1.22 |

The long central fibers showed higher values of elongation and tension compared with the peripheral short fibers. The fiber quality from younger leaves was superior to that from the mature leaves. As is usual, the quality of long fibers was superior to that of the short ones.

## DISCUSSION

The development and lignification of fiber cell walls increases from the base to the tip. The fiber bundles are younger in the central "cogollo" at the base, middle and leaf tips compared with all the positions in the middle whorl and external leaves. They are younger at the base and older at the tip; therefore, the fiber cells in the mature external leaves are highly lignified and produce hard fiber filaments which are difficult to manage.

As shown in the photomicrographs of figures 10 to 14, the secondary cell wall formation is associated with sequentially distinct processes which include the condensation and accumulation of protoplasmic granules and their deposit in the cell wall materials in small patches, both in spiral and reticulate patterns.

The present study supports the findings of Datta (1) for *A. americana*, in that fiber cells in *A. lecheguilla* develop by modification of ground parenchyma at the meristematic leaf base. Thin-walled parenchyma at the leaf base undergoes repeated mitosis with the accumulation of protoplasm to form the fiber initials, which then elongate vertically. The pattern of development resembles that of *A. americana* (1) and Lozano (6 and 13) found that in *A. lecheguilla* there is a gradual accumulation of dense protoplasmic contents and of the protoplasmic micellae in the secondary cell wall.

The fiber strands obtained from the partly mature and younger leaves are of higher quality than those of the mature leaves. The leaves of second whorl might be of equal or of better quality than those of the central core, although the common practice is to exploit the central "cogollo" only.

The fiber quality differs at the base, middle and top of the leaves, as the degree of lignification increases gradually from the leaf base to the tip, and the fiber is softer in the basal regions compared in the distal ones. Owing to high degree of lignification of the fibers obtained from the external mature leaves, these fibers can be used for machine scrubbing brushes and other rustic uses.

## CONCLUSIONS

Lechuguilla shows large variability in morphological types and abundance in different edaphic conditions. The development of fiber cells and fiber bundles in lechuguilla follow sequential processes of morphogenesis. Fiber cells in lechuguilla develop at the base of the developing leaf as a circular to semi-circular ring of procambial cells surrounding an undifferentiated mesophyll. Gradually this ring assumes a lunar shape with the development of xylem and phloem on the concave side. Cells of the inner, undifferentiated meristem accumulate dense protoplasm and are gradually transformed into fiber cells starting at the concave side and progressing to the convex side of the semilunar undifferentiated meristematic ring. This is finally transformed into a fiber bundle, followed by vertical elongation of the fiber cells and the condensation of protoplasm, thus forming the secondary cell wall of the fiber cells.

Fiber filaments are formed by the union of developing fiber cell arising from the meristematic leaf base traversing the leaf mesophyll. These fiber filaments converge at the apex to form the apical spine. The filaments obtained from central leaves ("cogollo") are younger and of better quality compared with those from the peripheral mature leaves. However, the fibers from external leaves may be used for rustic purposes like brooms, scrubbing brushes, etc. Due to irregular and excessive harvesting, lechuguilla is in danger of extinction. Therefore, proper care should be taken to save this valuable natural resource.

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