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FIBER QUALITY VARIATION WITHIN A COTTON PLANT AS AFFECTED BY GENETICS AND ENVIRONMENT

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Abstract

Fiber quality, which has a major impact on selling price, is currently defined by seven parameters. Several of the components, such as length, length uniformity, strength and micronaire have significant genetic controls. Others such as color, leaf trash, and extraneous material are greatly influenced by the environment during maturation and harvest. Fruit set occurs over a 25-35 day period with individual fruit requiring 45-60 days to mature and open. Fiber development has two distinct phases during individual boll development. The first 18-22 days in the life of an individual fruit is the fiber elongation phase establishing maximum fiber length and also maximum fiber diameter, both of which have strong genetic control moderated by the environment. Both temperature and water supply affect fiber elongation and final fiber length. Beginning shortly before fiber elongation is complete is the deposition of the secondary wall consisting of essentially pure cellulose. The cellulose deposition phase occurs throughout the 24 hour day and the density of the daily ring is very temperature dependent.

Box mapping techniques were used over a three year period across a range of genetic types, including stripper and picker varieties, and production management systems to provide a wide range of both genetic and environmental conditions to evaluate in-plant variation in fiber quality traits. Fruit size and fiber quality determinations were made for each fruiting position by nodal location and fruiting site on each fruiting branch. HVI analysis was used to determine the quality parameters of interest.

Fiber length exhibited significant variation among cultivar means as expected. The range in fiber length within a plant from fruit-to-fruit and among means across environments varied by 3/32 inch from the bulk sample mean. Fiber strength also exhibited significant genetic variation. The environmental variation was inversely proportional to the change in micronaire, reflecting the problem of measuring bundle strength rather than individual fiber strength with HVI. Micronaire mean values exhibited minor differences among varieties within an environment, but very large environmental variation existed within variety and within plant. Micronaire values ranged from >5.0 at the bottom fruiting nodes to <3.5 at the top of the plant. All cultivars evaluated were capable of producing fiber with micronaire values ranging from >5.0 to <3.5 depending on the physical environment, particularly the night temperature during secondary wall formation of individual fruit. Water supply also affected micronaire distribution within plants. Under rain fed conditions, micronaire varied considerably with no apparent pattern due to nodal position or fruiting site on a branch. Under well-watered conditions micronaire was lower than under dry land conditions, but more consistent within the plant responding only to temperature.

Fiber length and strength are strongly controlled by genetics with a range of 3/32's inch from the cultivar mean due to environment. Strength is also strongly genetically controlled and bundle strength is strongly influenced by micronaire. Mean micronaire values do reflect genetic control, but the magnitude of variation in both mean values and within-plant values are largely affected by temperature during cellulose deposition in individual fruit.

Introduction

The primary fiber traits of length, strength and micronaire have both genetic and physical environment affects. Fiber length and strength are strongly affected by genetics with significant differences in mean fiber length among cultivars. Fiber elongation begins one or two days prior to fertilization of the ovule and continues for 18-22 days post-anthesis. The two major environmental components that affect fiber length are water supply and temperature. Fiber elongation is primarily a function of the influx of water driven by an osmotic potential gradient developed within the fiber. Both the supply of water to the fruit and/or the influx of organic solutes in the fiber can reduce the rate of fiber elongation and the final fiber length. Individual fibers on each seed within a fruit and individual fruit on a single plant are subject to specific environmental conditions that affect final fiber length.

Temperature has both a direct and an indirect effect on fiber length. Temperature directly affects the metabolic rate with the optimum temperature for fiber elongation reported to be around 30^{o}C and the minimum and maximum 15 and 35, respectively. Depending on location within the cotton growing regions of the world and the growing season conditions, individual fruit on a plant can be subject to a fairly wide range of temperature conditions during the fiber elongation phase.

It is not well defined weather the fiber elongation period is variable due to environmental conditions. It would be logical to assume that if the variation within a cultivar is fairly small across environments and within a plant that final fiber length is genetically controlled and of primary importance, and the rate which is environmentally controlled is variable and of secondary importance.

Fiber strength is determined by the layering angle and the degree of cross-linkage (hydrogen bonds) among cellulose microfibrils within both the primary and secondary walls. Strength has a very strong genetic influence. Bundle strength (HVI measurement) is inversely related to micronaire due to the measurement being based upon on equal fiber mass rather than an equal number of fibers.

Micronaire which is an indirect measure of the linear density of the fiber has a strong genetic component related to fiber circumference (or perimeter) which is indicative of fiber standard fineness and a strong environmental (primarily temperature) influence on cellulose deposition. Cultivar means across environments reflect genetic variation in fiber circumference. Maximum and minimum values across environments reflect environmental impacts, largely related to temperatures during maturation of an individual fiber. High temperatures (especially night temperatures) result in high linear density due to a high percentage of crystalline cellulose in the secondary wall. Low night temperatures result in lower density due to a high percentage of amorphous cellulose. Cotton growing regions exhibit large difference in diurnal temperature conditions during the cellulose deposition phase of each fruit on an individual plant resulting in considerable variation in mean micronaire within a cultivar each year.

The purpose of this manuscript is to define the degree of genetic variation in fiber quality traits and the magnitude of variation due to environmental conditions.

Materials and Methods

Over the course of the past 10 years we have collected a large amount of data on cultivar – environment interactions affecting fiber quality especially length, strength and micronaire. Cultivars evaluated have represented a wide range of both picker and stripper types. Environments have reflected years and plant density, water supplies, and fertility treatments within years. Both means cultivar fiber data as well as within plant responses have been evaluated. The within plant responses have been developed using a box-mapping approach with a minimum plant number reflecting 0.001 acre and yields ranging from less than 200 pounds per acre to over 2000 pounds/acre for each cultivar over the course of years and environmental conditions. Fiber quality parameters were measured using HVI analyses. Cultivar traits are presented as mean, standard deviation, maximum and minimum. A minimum of 50 site years of data were used to develop the fiber traits for each cultivar.

Results and Discussion

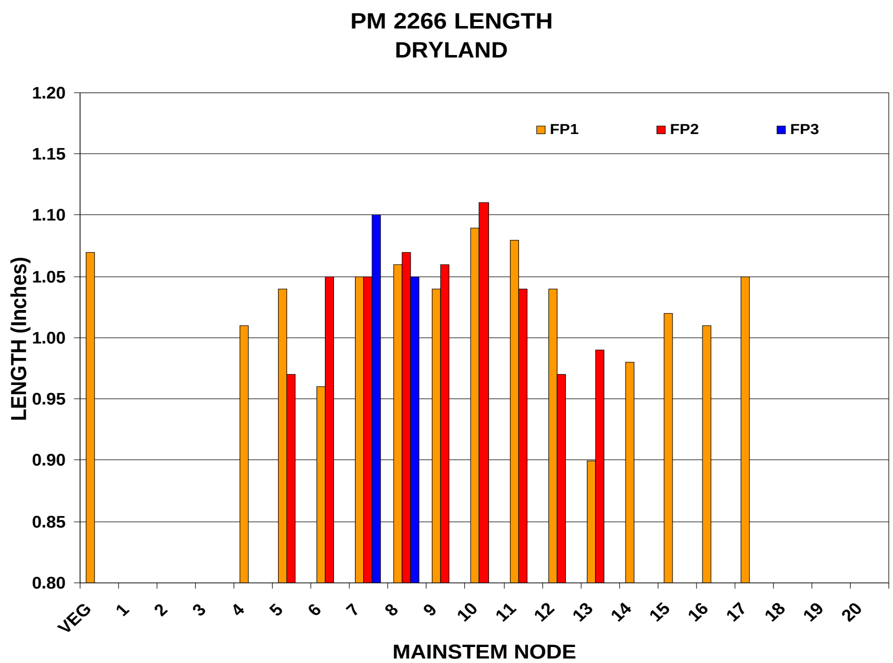
Mean fiber length is strongly influenced by genetics with a range from 1.15 inches to less than 1.0 inch among commercial cultivars (Table 1). Over the >50 site-years of data used to calculate means for each cultivar, standard deviations ranged from 0.05 to 0.15. No significant relationship existed between mean fiber length and standard deviation. Maximum and minimum values, in our opinion, reflect the genetic potential (maximum) and the maximum environmental reduction (minimum). Across most of the cultivars evaluated the range was approximately 0.1 inch relative to the mean fiber length.

Table 1. Genetic variation in mean fiber length (Inches) and impact of environment on variation.

CULTIVAR	MEAN	STD. DEV.	MAX	MIN
ACALA 1517	1.14	0.05	1.24	1.01
ST LA 887	1.12	0.04	1.18	0.97
DES 119	1.11	0.04	1.19	1.04

D&PL 5415	1.10	0.04	1.18	0.96
D&PL 50	1.10	0.05	1.19	0.98
ST 474	1.07	0.04	1.17	0.96
ST 132	1.05	0.05	1.15	0.92
PM HS 200	1.06	0.06	1.18	0.87
PM HS 26	1.04	0.05	1.14	0.89
PM 145	1.00	0.06	1.10	0.85

Water supply represented the major cause of variation within both mean fiber length and within plant variation (Figure 1). Under rained conditions in West Texas, individual fruit on a plant had fiber length variation of 0.2 inches from fruit to fruit. No consistent vertical or horizontal pattern existed, reflecting the specific environmental conditions affecting each individual fruit during the period of fiber elongation. The fact that considerable fruit to fruit variation existed within a plant would suggest that the fiber elongation period is fixed in time and factors that affect the rate of elongation have major impact on final fiber length.



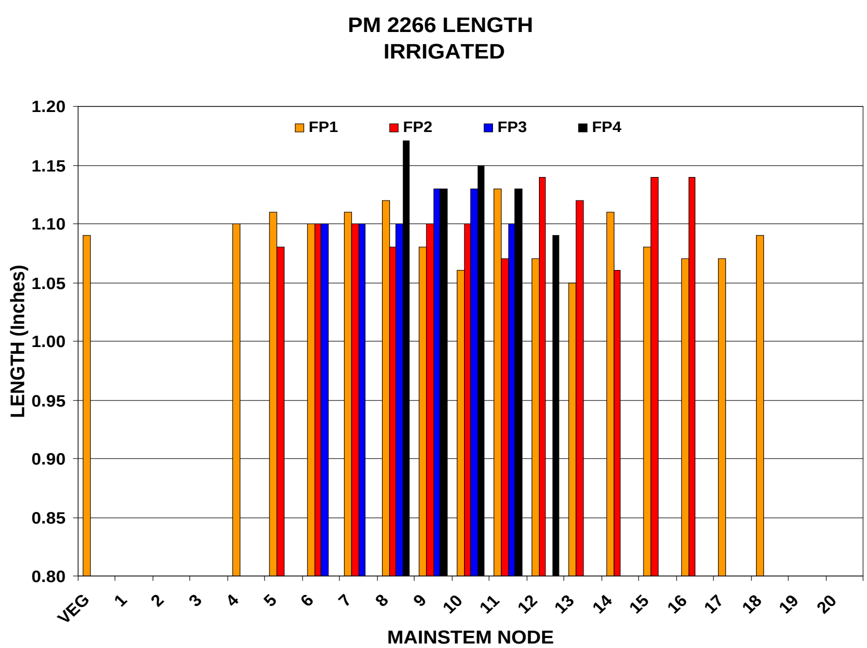


Figure 1. Fiber length variation within plant due to water supply.

Fiber strength means varied among cultivars, independent of fiber length and micronaire, reflecting genetic influences on microfibril arrangement within both primary and secondary walls. The variation within a cultivar across environment was less than observed for fiber length as indicated by the standard deviation relative to the means and the maximum and minimum for each cultivar (Table 2).

Table 2. Genetic variation in mean fiber strength (g/tex) and environmental impact on maximum and minimum values

CULTIVAR	MEAN	STD. DEV.	MAX	MIN
ACALA 1517	30.62	3.04	39.10	24.30
ST LA 887	29.93	2.24	34.50	25.50
DES 119	27.91	1.97	32.50	24.70
D&PL 5415	28.30	2.28	34.50	23.90
D&PL 50	25.57	1.89	31.00	20.60
ST 474	27.68	1.86	32.50	24.70
ST 132	27.52	1.70	30.60	23.20
PM HS 200	28.50	2.02	33.50	23.40
PM HS 26	29.01	2.31	36.80	24.00
PM 145	26.07	2.03	30.60	21.80

Micronaire is an indirect measure of specific surface and is related to the linear density (mass/length) of the fiber. Indeed, Lord (1956) showed that the product MH (M = maturity ratio, H = fineness in millitex) was a quadratic function of the micronaire index (Lord, E. 1956. Airflow through plugs of textile fibers. Part II. The micronaire test of cotton. Journal of the Textile Institute, 47: T16-47.). Linear density is influenced by the cross sectional area (without lumen) of the fiber which has a strong genetic influence due to fiber circumference. Cellulose deposition in the secondary wall is strongly influenced by night temperature as it impacts the degree of crystallinity. Cultivar means for micronaire reflect differences in cross sectional area of the average fiber on the plant across all environments (Table 3).

Table 3. Cultivar means and variances in micronaire values due to environment

CULTIVAR	MEAN	STD. DEV.	MAX	MIN
ACALA 1517	4.33	0.41	5.20	3.30
ST LA 887	4.63	0.54	5.80	3.30
DES 119	4.72	0.48	5.60	3.70
D&PL 5415	4.59	0.82	5.60	2.50
D&PL 50	4.43	0.72	5.70	2.60
ST 474	4.79	0.60	6.10	3.50
ST 132	4.38	0.65	5.20	3.30
PM HS 200	4.07	0.57	5.30	2.50
PM HS 26	4.34	0.53	5.60	3.00
PM 145	4.12	0.67	5.40	2.70

Standard deviations are very large for micronaire reflecting the strong environmental impact on linear density of the cellulose. Essentially all cultivars evaluated are capable of exceeding both the upper and lower limits of the loan base (4.9 and 3.5, respectively) for micronaire reflecting the strong impact of temperature. Within plant variation for micronaire is also very large under both average temperature conditions (Figure 2) and under adverse conditions (Figure 3).

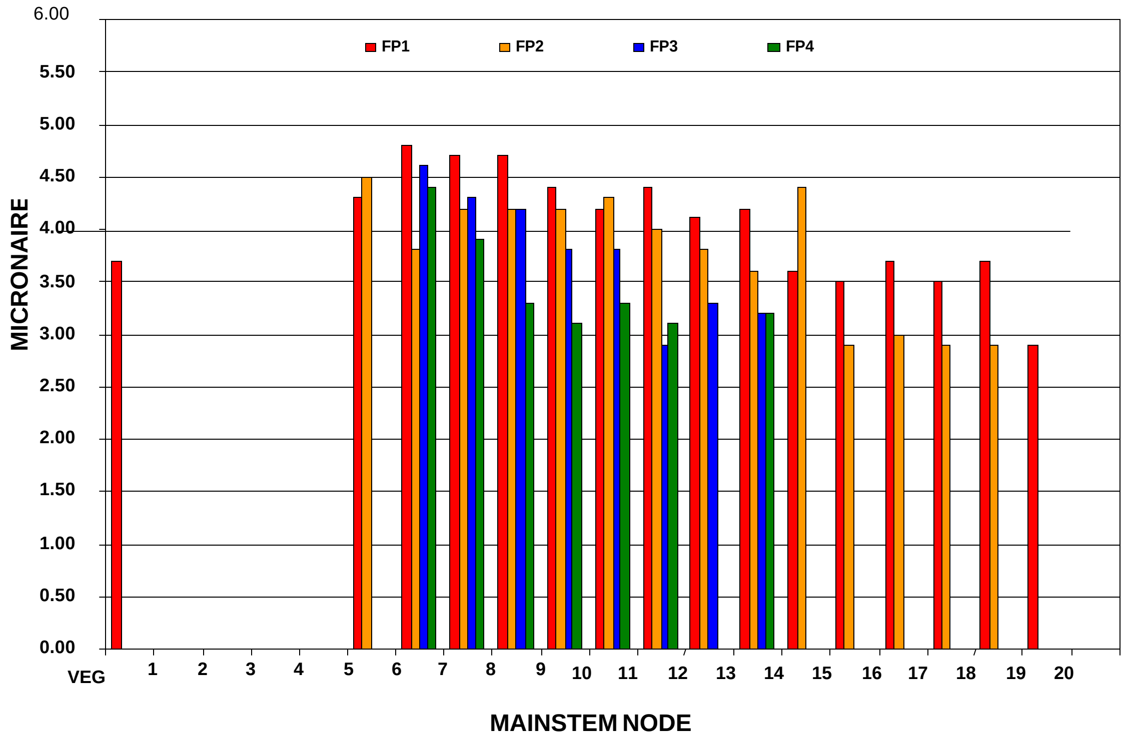


Figure 2. Within plant variation in micronaire under long-term average temperature conditions during boll development.

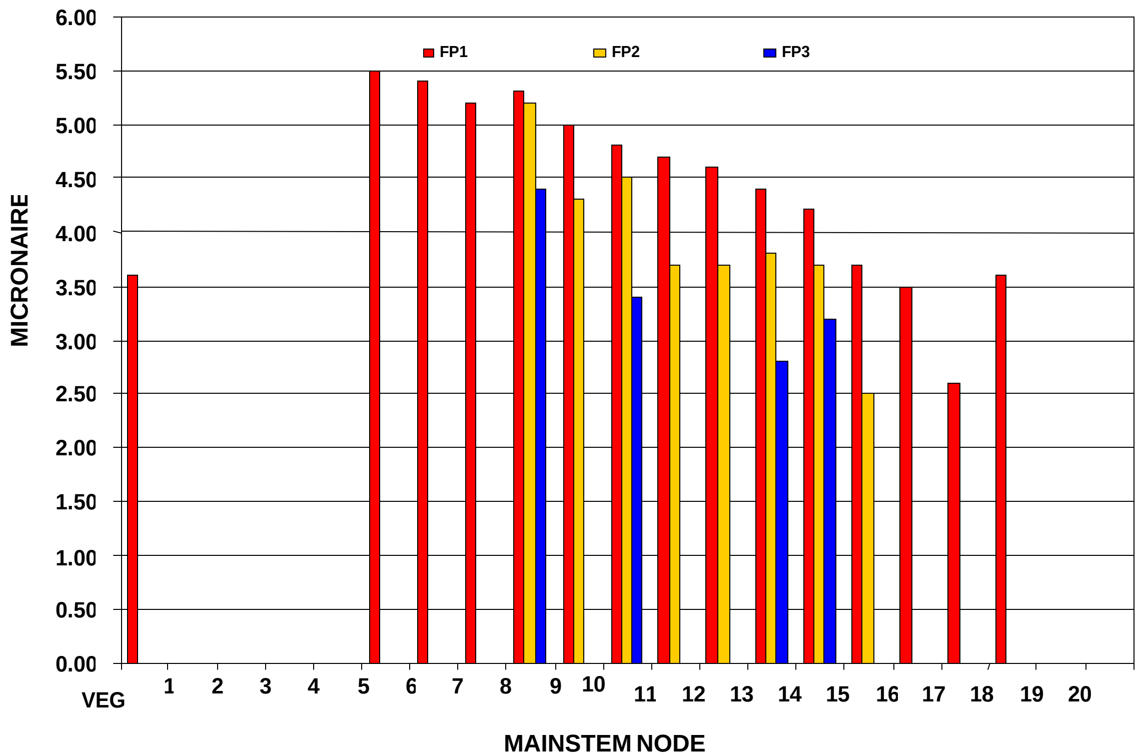


Figure 3. Within plant variation for micronaire under above average temperature conditions during boll development

On the Texas High Plains, cellulose deposition of the first-set flowers begins in late July and requires about 30 days for completion within an individual fiber. The last harvestable fruit are produced from flowers set in mid-August with cellulose deposition occurring from mid-September through October. Mean daily temperatures decline significantly during this time frame as compared with early set flowers. The greatest cause of the lower means temperatures are due to night temperature conditions. When night temperatures drop below 20^{o}C, cellulose density begins to decline becoming highly amorphous at temperature approaching 10 ^{o}C. Within plant variation is very large ranging from micronaire values in excess if 5.0 at the bottom of the plant to less than 3.5 at the top of the plant depending on the location of production and the year. The same variety grown in a different environment will have a different distribution and range of micronaire values from fruit to fruit.

Other fiber traits such as color and trash are largely a function of the weather conditions after the boll opens and fiber is exposed to the elements prior to harvest.

Summary and Conclusion

Fiber length and strength are primarily influenced by genetics. Mean fiber length exhibits significant genetic variability. The environmental impact is largely related to water supply during the elongation phase and can cause as much as a 0.1 inch reduction in fibers length of an individual fruit. No significant boll location effect (neither vertical nor horizontal) exists for fiber length. Rather, the physical environment existing during the elongation phase of each fruit determines the final fiber length.

Fiber strength is also strongly influenced by genetics. More variability exists in HVI measured strength (bundle strength) due to large variation in micronaire across environments than in actual fiber strength. An inverse relationship exists between bundle strength and micronaire.

Fiber micronaire does have a genetic component in fiber circumference which directly affects the cross sectional area. However, the temperature component during the cellulose deposition phase of an individual fiber has a greater impact on fiber micronaire than does the genetic component. Fibers, developing secondary walls when the night temperature exceeds 20^{o}C have a high degree of crystalline cellulose; whereas those fibers developing secondary walls at temperatures below 15^{o}C have a high degree of amorphous cellulose. The within plant variation ranges from greater than 5 to less than 3.5 depending on the genetically controlled fiber circumference and the temperature during secondary wall development of each fruit.