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MORPHOLOGICAL DEFECTS OF LIVING COTTON HAIRS IN DEVELOPING COTTON BOLL

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Abstract

In an example of some cotton sorts in-vivo observations were carried out of native defects originating in cotton hairs during their development in a non- opened cotton boll. It is shown, that the appearance of morphological structural defects in cotton hairs is related to the features of their packaging in a fruit; cotton boll during the formation of so-called segment of cotton boll. A mechanism explaining the cause of the morphological defects origination in fibers is proposed. . It is based on consideration of hydrodynamic properties of cytoplasm in living cotton hairs at the places of their bending.

Introduction

Cotton fiber, made up of 98% pure cellulose, is important biopolymeric material and is widely used in different fields of human activity (Ott et al. 1954, Usmanov and Nikonovich 1962, Balls 1965, Tarchevskiy and Marchenko 1985). The biology of cotton fiber, its fine structure, and physical, chemical and technological features have been studied for over a hundred years (Farr 1937, Franz and Meier 1963, Vlasova 1974, Popova 1975, El-Sahhar et al. 1982). Much research has been devoted to the origin of defects in cotton fibers and to the degradation of its properties during crop gathering, storage and primary technological processing (March 1957, Hadjinova 1963, Rahimov and Rudenko 1976). One of the questions that has remained unsolved is why, during the development of the fiber, does an unopened cotton boll already contain a considerable percentage of distorted cotton hairs? What is the nature of the origination of these defects?

Few investigations have specifically addressed these questions. Farr (1937) notes that the number of defects is initially low but increases sharply when the density of fibers increases during boll ripening. The highest number of defective hairs reported is 93.6 for *Gossypium hirsutum* and 15.2 for *G. barbadense*. In another detailed investigation (El-Sahhar et al. 1982), thirteen Egyptian cotton types were analyzed. The authors categorize the defects observed as follows: thin filament, bent, knot, small dowel, large dowel (> 80 microns), branched and protuberant fibers and reported the frequency of their appearances. Krakhmalev et al. (1987) studied the fiber defects of five Asian cotton types and lists small “dowel” (approximately 27 %) and “bent” (approximately 21 %) as the most frequent aberrations. Environmental stress factors, such as high temperature and insufficient water supply, during the ripening of fibers sharply increased the frequency of defects. For example, cotton grown under midday temperatures up to 45 °C, in superheated soil in vessels, and with only one watering per day, showed approximately 15.4 % defective hairs on the surface of the cotton boll segments and between 37 and 52 % defective hairs on the seeds. The defects increased from the halasal part (12.5 %) of a seed to the micropil part (24 %).

The naturally occurring defects in cotton hairs reduce the uniformity and, thus, the quality of yarn. The quality of yarn and the resulting textile depend largely on the strength of the fiber (Hadjinova 1963). Small differences in fiber strength can lead to tearing during spinning. Consequently, these seemingly small defects found in cotton fibers have a significant effect on product quality and, ultimately, on the economy of countries with a large cotton market. The purpose of this investigation is to analyze the origin of these structural defects of cotton hairs through in vivo-observations.

Materials and Methods

Plant Material

Hairs of the following cotton species and cultivars were investigated: *Gossypium hirsutum* L. (Tashkent-1, 108-F, Kizil-Ravat), *Gossypium barbadense* L. (C-6030, C-6524), described by Dariev and Abdullaev (1985), and *Gossypium herbaceum*, the coarse-fibered form Turfan Guza described by El-Sahhar et al. (1982). Plants were grown in a local plot on clay-fertilized sierozem with regular watering. Opening flowers were labelled daily at the same time (about 10:30 AM) and examined under a Neophot-2 universal optical microscope (Carl Zeiss, Germany) in reflected light at a large magnification. Observation of the features of cotton hair structure at the earliest stages of development, during cotton boll packing, was made microscopically under 910 to 3700 X magnification. In all cases, labelled fruits were collected with a considerable segment of stem attached. Cotton bolls of 5, 10, 15, 20 etc. days after flowering were used. A small hole (hole size ~1-1.5 mm) was punctured in the green bolls for in vivo-observations that allowed the moisture to remain in the bolls. These samples were placed under the Neophot-2, connected to a video camera. Through this arrangement, not only static defects but also the formation of these defects during the growth process could be recorded. Hairs were not damaged by this procedure.

Microscopic observation

The method of replica imprints (Usmanov and Nikonovich 1962), which allows a precise reproduction of the structure of the hair surface was used. Replica imprints were obtained by spraying aqueous solutions (for example, gelatine), which tightly coat the surface of living cotton hairs. After detachment of the film, hair imprints were examined in reflected light. This observation technique allows for obtaining a panoramic image of the surface of living cotton boll segments. In some cases, for the investigation of the fine structure of the cell wall of cotton hairs, a 10 % NaOH solution or Sveyserov's reagent was used (Zakoschikova 1931). No less than 1000 hairs per developmental stage (up to complete maturation) were studied. Cotton plants with an average statistical quantity of seeds of 28 to 32 seeds (4 lobular cotton bolls) were investigated. The hairs, their packing and the disturbances of their morphological structure were studied in the surface layers of living lobes after careful removal of the sepals.

Results and Discussion

The defects observed in our investigation (see Figure 1) are of the same type as those previously described (Andersen and Kerr 1938, Franz and Meier 1963, El-Sahhar et al. 1982, Krakhmalev et al. 1987). This uniformity in defects observed in different genotypes under different environmental conditions (latitude, soil, etc.) convincingly indicates that there is an inherent factor common to all these defects. Previous authors (Farr 1937, Andersen and Kerr 1938, Franz and Meier 1963, El-Sahhar et al. 1982) suggested that the defects are related to the number of cotton hairs per volume unit of a cotton boll and their packing at high density. High density could be the result of a heterosis-like effect after hybridization.

Cotton plants usually contain between 18 to 45 seeds (3-5 lobular cotton bolls) (Vlasova and Krakhmalev 1984, Krakhmalev 2000). After fertilization, the ovary initially grows faster than the developing seeds allowing the seed hairs to develop in sufficient space. Approximately at day 5-7, the seed hairs reach the internal boundary of the ovary and are forced to bend and grow in the opposite direction at approximately day 7 to 9. As there is already a fibrous cover on the seed at this time, bent hairs are interwoven with the fibrous cover of their own or neighboring seeds. This contact-coupling configuration remains even after its discharge from the cotton boll. The number of hairs, including lint hairs, of ripe seeds from different commercial varieties varies from 90 thousand to 115 thousand (Krakhmalev and Sultanova 1983). Given that each separate lobule consists of 6-9 seeds, up to a million hairs must be packed into a limited space resulting in multiple bends and the typical zigzag-like symmetrical appearance as shown in Figure 2a.

From day 15 to 20 and on until full ripening there are two instances where the dense packing (Figure 2b) show some free space: one, in front of the growing hair tip, where the invading hair pushes apart the already packed hairs (Figure 2b) and two, where hairs collectively change direction (Figure 2c) (Vlasova and Krakhmalev 1986).

Through the use of our video recording system, we were able to observe not only apical growth (Figure 2d, hair 2), but also directly monitor the occurrence of defects in cotton hairs. First as the defects appeared as local bulges of a cell wall, then as small and large dowels. Figure 2d simultaneously shows the linear tip growth of the cotton hair (hair 2) and the point of a sharp turn of another hair (hair 1). At the turn the defect appeared first as cell wall bulging, then as a small and consequently large dowel. As we can see from the fine structure of the apical part of cotton fibers, an ordinary fiber and a defective one have identical growth mechanisms. It is shown that the growth and lengthening mechanism of cotton hairs is connected to the periodic appearance on their apical parts of microscopically plastic convexing, which rhythmically occurs and expands to the natural diameter of cotton hair. Thus, our work visually demonstrates that the reason for the formation of the majority of structural defects in hairs is their sharp bending. The microscopy demonstrates that the structural defects arise in such hairs necessarily.

Observations of living cotton hairs (Krakhmalev and Zakirov 2000) have shown that groups of hairs but not individual hairs often undergo a sharp change in growth direction. Simultaneously, the apices of the growing hairs on one layer form uniform rows with the hairs on other layers. Each layer forms straight lines along the inner surface of the cotton boll. When the group of hairs sharply changes growth direction, their lengthening is equal. Despite the apparent heterogeneity of their population and the different time of their emergence, we observe a moment when all

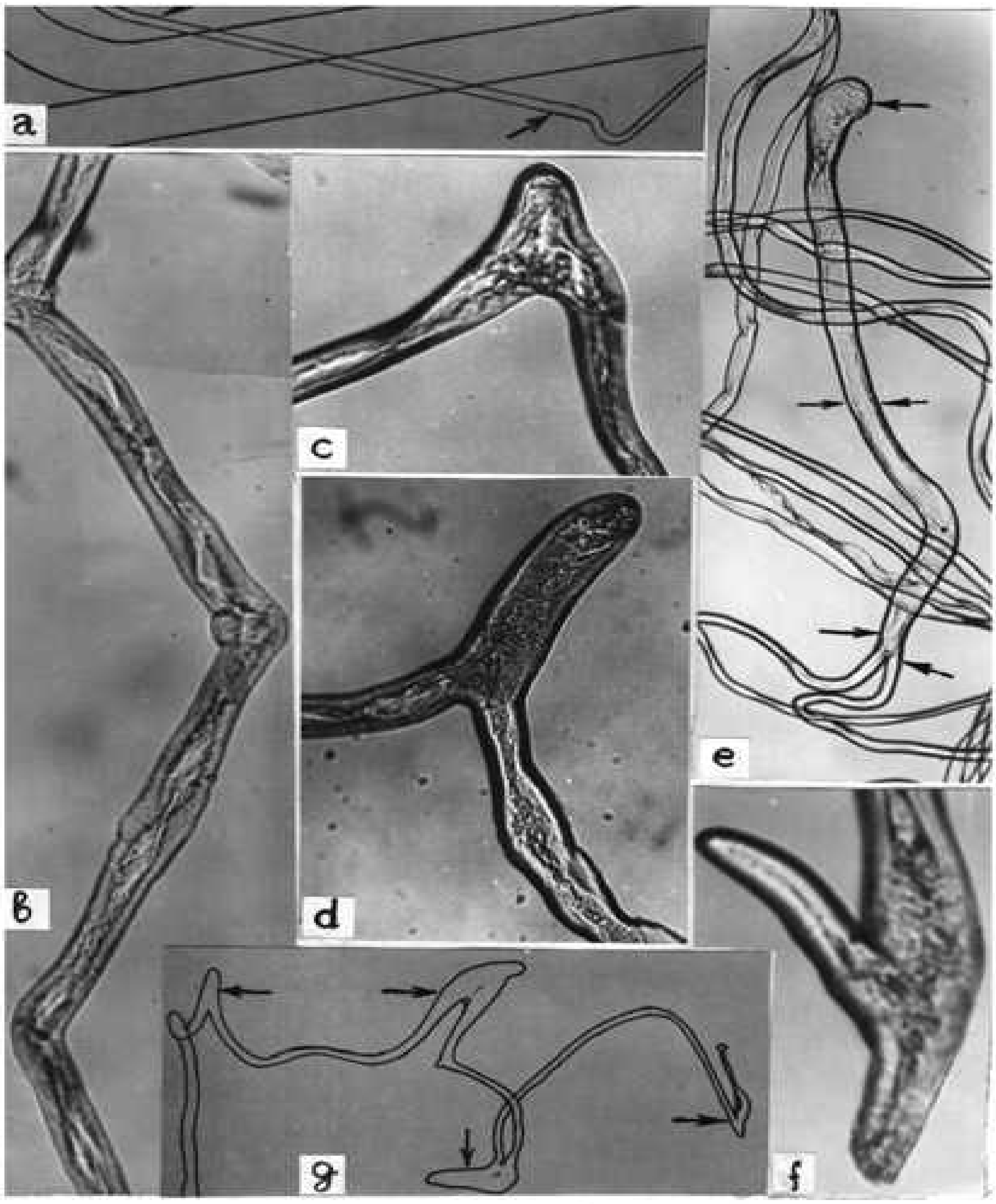

Figure 1. Defects observed in cotton hairs of plants (*G. hirsutum* cv. Tashkent-1) raised under optimized culture conditions. a - thin filament, x370; b - zigzag-bent fiber, x260; c - short spur, x200; d - long spur, x200; e - forked fiber, x260; f - protuberant fiber, x350; g - multiple spurs, x370hairs, even those far from each other, suddenly participate simultaneously in the change of growth direction and demonstrate symmetry of hair arrangement in the various layers.

Hairs that have sharply (90-180^{o}) changed growth direction (Figure 2d, e) often show deformations at the bending site. In figure 2d, a protrusion at a 180^{o} bend is shown (labeled 1) mimicking the mechanism for hair tip growth (2 in Figure 2d) as described by Frenkel (1956). The structural research demonstrates (Figure 2d) that the defects apparent in cotton hairs are mainly related to the places of their zigzag-like bends. We propose that the cause of the formation of defects in cotton fibers is the same: the local extrusion of a cell wall (at the bending site) is due to an increase in its plasticity. The size and form of an extrusion depends on the duration of the development of the extrusion and the stage at which it forms. It appears that all deformations described that occur during cotton hair growth can be reduced to two types: 1. thin filament and 2. fibers with dowel-like extrusions. The mechanisms of origin of these two types of defects are different.

Thin filament occurs as a result of a disturbance of the natural process of smoothening that normalizes the fibers' appearance. This process includes cell wall thickening and leveling of protrusions. Cotton fiber growth appears to be a pulsing process. Each pulse is accompanied by the formation of a band of transverse spiral-like microfibrils. In normal hairs pulse-related bulges disappear while the cell wall is thickening. However, in some cases, this thickening does not occur, most frequently in Kizil-Ravat, and a thin filament fiber as shown in Figure 2f is the result. The diameter of such fibers is usually half to a quarter that of normally developed ones.

Dowel-like extrusions form in a different way. In places of sharp bending with the growth direction changing by 90^{o} and greater, including total folding, significant pressure changes occur (Altshuler and Kiselev 1975). In accordance with Frenkel (1956), under such conditions maximal pressure may be concentrated to a limited area or even a single point. Pressure increases along the path of cytoplasmic streaming is linked to deviations of linear movement. In the apex of hairs as well as in the tip of a sharp bending point, where resistance increases (by some order), cytoplasmic streaming has a turbulent character. As a consequence, cytoplasmic particles preferably knock against the tips contributing to either tip growth or spur formation. Furthermore, at some distance from the tip or bend, the pressure in the moving cytoplasm sharply decreases to values required for overcoming the forces of frictional resistance. As a result of these two mechanisms, the plasticity at the tips significantly increases. If such cell wall protrusions occur during early stages of hair development the protrusion may indefinitely elongate resulting in a bifurcated hair. Such a bifurcated hair does not contain internal walls, that is, it remains unicellular.

Conclusion

In conclusion, fiber defects found in cultivated cotton are a consequence of the high fiber content of these varieties and the resulting need for densely folded packaging. It seems to be a price that has to be paid for increasing yield.

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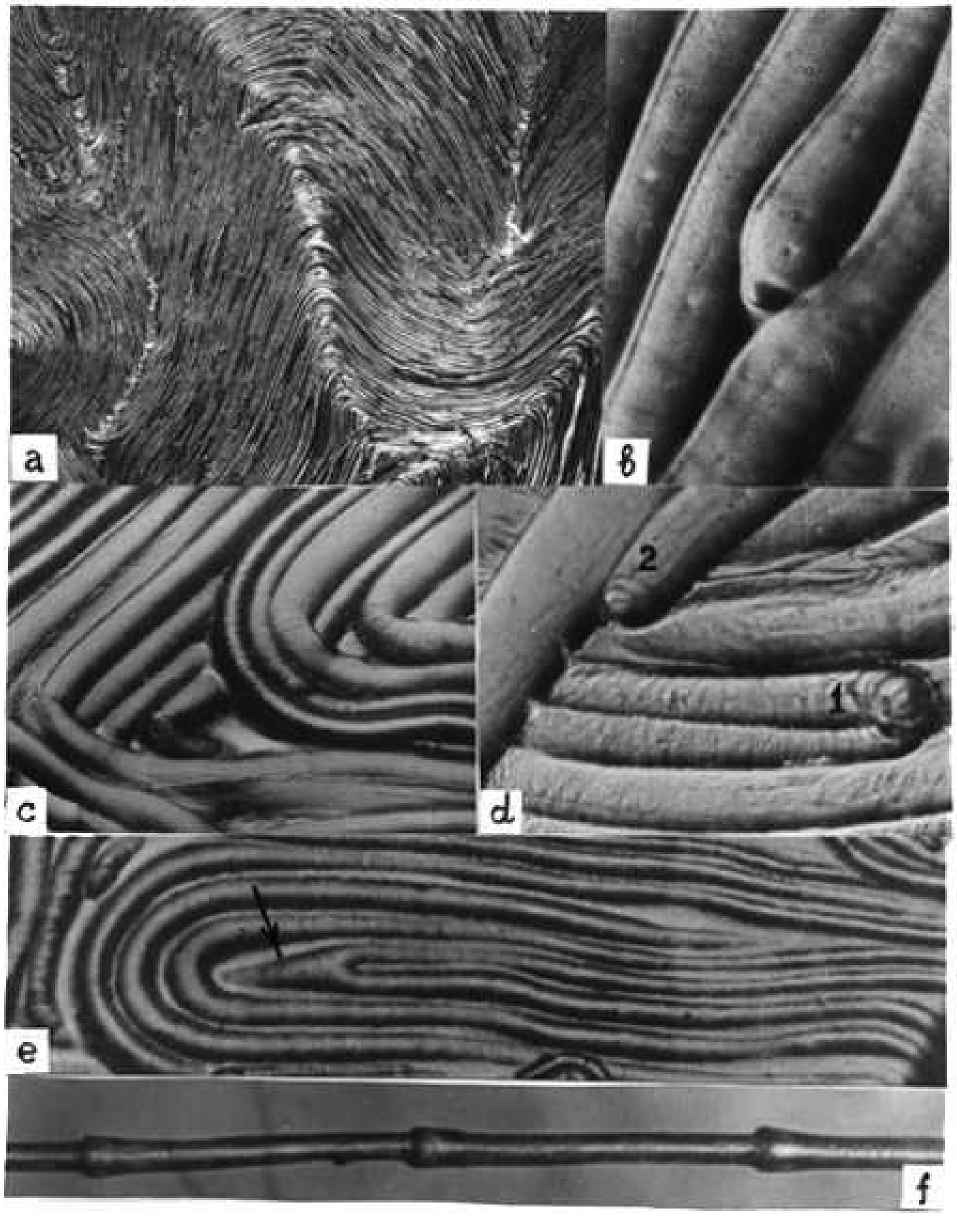

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Figure 2. Observations of growth features of cotton hairs during the formation of cotton boll segments (replica imprint, see Materials and Methods) a - typical packing of cotton hairs on the surface of cotton segment on day 17 after flowering (Tashkent-1, x45); b - section of straight-growing hairs (108-F, x1000); c - section of bended-growth (C-6030, x500); d - section with sharply-bent hair (1) and apical tip (2) (Turfan guza, x1200); e - spur

formed at bending site (Tashkent-1, x500) f - thin filament showing an inhibition of cell wall thickening thus, leaving lateral extrusions. Cotton boll opened 45 days after flowering (108-F, x1000)