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Internal Structure and Pigment Granules in Colored Alpaca Fibers

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Abstract: Alpaca fibers have some distinct properties such as softness and warmth, which have not been fully understood in combination with the fiber internal structures. In the present investigation, the internal structures of alpaca fibers have been closely examined under the scanning electron microscope (SEM), especially in the longitudinal direction. The results showed that numerous pigment granules reside loosely inside pockets in brown and dark-brown alpaca fibers. These pigment granules were mainly distributed inside the cortical cells, the medullation regions as well as underneath the cuticles. Their size in the brown alpaca fibers was smaller and more uniformly round than in the dark-brown fibers. These granules in colored alpaca fibers loosen the bundle of cortical cells, providing many crannies in the fibers which may contribute to the superior flexibility, warmth and softness of the fibers. Moreover, there are no heavy metal elements found in the granules. The mordant hydrogen peroxide bleaching employed could eliminate the pigment granules and create many nano-volumes for further dyeing of fibers into more attractive colors.

Keywords: Alpaca fibers, Pigment granules, Morphology, Mechanical properties, Particle size distribution

Introduction

The development of the alpaca fiber industry has been facilitated by research into fiber properties and processing performance [1-6]. The physical properties such as fineness, staple length, strength, compression, and surface feature have been broadly investigated in comparison with wool. The processing performance of alpaca fibers in scouring, bleaching and dyeing, top making, yarn spinning, and knitting/weaving has also been investigated. The superior flexibility and soft handle are unique attributes for alpaca fibers. Warmth is also claimed to be a superiority of alpaca fibers [7]. Alpaca fiber is generally regarded as a better heat insulator than wool due to the high content of hollow medulla [8], which may contain more air-holes in the fiber than in the non-medullated fiber. However, the precise reason for these particular attributes of alpaca fibers has not been comprehensively explored in combination with the fiber internal structures, although it is believed that the fiber surface feature, fiber diameter and fiber rigidity play an important role [2,3,5].

Alpaca fibers usually have a larger diameter than wool, customarily with 28 %-67 % medullation. The average diameter is around 26 μm and the average staple length 100 mm [2]. The differences between alpaca varieties in the fiber morphology as well as other physical properties have been investigated in relation to alpaca growth [8-13]. For dark colored alpaca fibers, bleaching was usually required for the reduction of the depth of color shade and for the preparation of dyeing fibers with bright colors [1,14]. The results showed that the bleached brown or dark brown alpaca fibers could be dyed with more attractive medium or deep colors which may add value to dark colored fibers [1,2,5]. But the effects of bleaching on the fiber internal structures have not been given in these studies.

Laxer and Whewell [15] studied the melanin found in the form of granules in pigmented animal fibers including alpaca fibers. The report showed that melanin granules are usually deposited in rapidly dividing matrix cells of skin. Therefore, the fiber-forming cells in wool and hair follicles contain pigment prior to keratinization. Further examination of the chemical inertness of the melanins suggested that the melanins are polymers of high molecular weight and are also closely associated with heavy metals, especially iron. Mordant hydrogen peroxide bleaching with Ferrous Sulphate ($FeSO_4 \cdot H_2O$) was used as an effective method to remove melanin pigments. The absorption mechanism of iron by the melanins and the effect of the bleaching on pigmented alpaca fibers were intensively examined. The melanins were also isolated by dissolving the fiber keratin and the size was measured before and after hydrogen peroxide bleaching. The result showed that the size of the bleached granules become smaller than the originals. The general shape of melanin granules for coarse alpaca fibers was viewed as an elongated egg-shaped column.

In the present research, alpaca fibers in white, brown, and dark-brown colors were examined respectively in cross-sectional and longitudinal directions under the scanning electron microscope. The fiber internal structures were closely investigated by cutting them into thin sections. In particular, the natural pigment granules found in colored alpaca fibers were discussed in relation to the fiber properties such as softness, warmness and dye ability.

Experimental

Greasy fibers from two varieties of alpaca - Huacaya and Suri, were used in the present research. The fiber color features and diameters are listed in Table 1.

All fibers were scoured using a conventional wool scour-

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Table 1. Color and diameter of alpaca fibers selected

Alpaca variety	Color feature	Diameter (μm)	CV of diameter (%)
Suri	White	27.2	27.8
Huacaya	White	25.3	26.3
Huacaya	Brown	25.3	26.3
Huacaya	Dark-brown	25.1	28.9

ing system. Bleaching for the colored alpaca fibers was further carried out using a mordant hydrogen peroxide bleaching system. The bleaching details were fully described elsewhere [1].

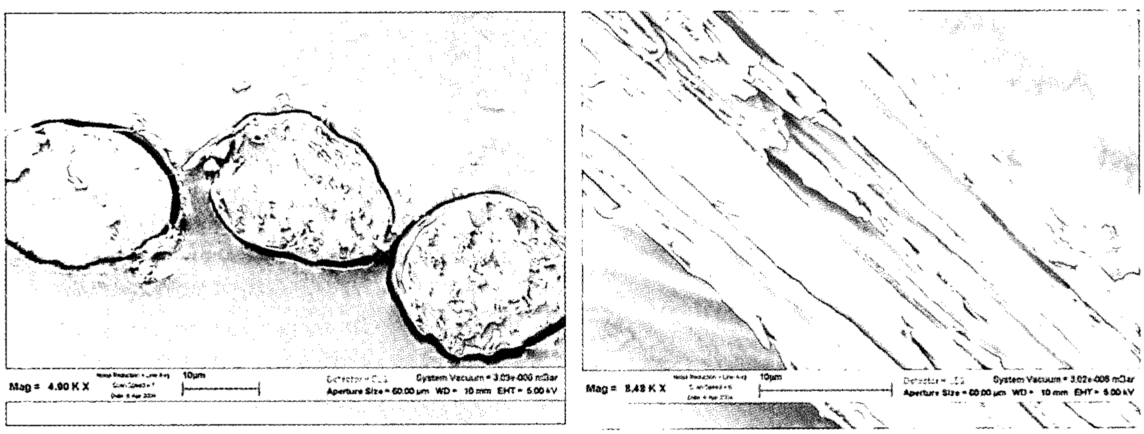
Fiber sections were prepared in both longitudinal and cross-sectional directions for observation by the scanning electron microscope. The fibers were embedded in the Technovit 7100 resin (Heraeus Kulzer, Germany) and then cut into sections of 2 μm-8 μm in thickness. A Leo1530 scanning electron microscope was employed for imaging and obtaining the energy dispersive x-ray analysis (EDS) spectrum. A 15KV accelerating voltage and 35-degree take-off angle were set for the x-ray test.

Results and Discussion

Distribution of Pigment Granules in Alpaca Fibers

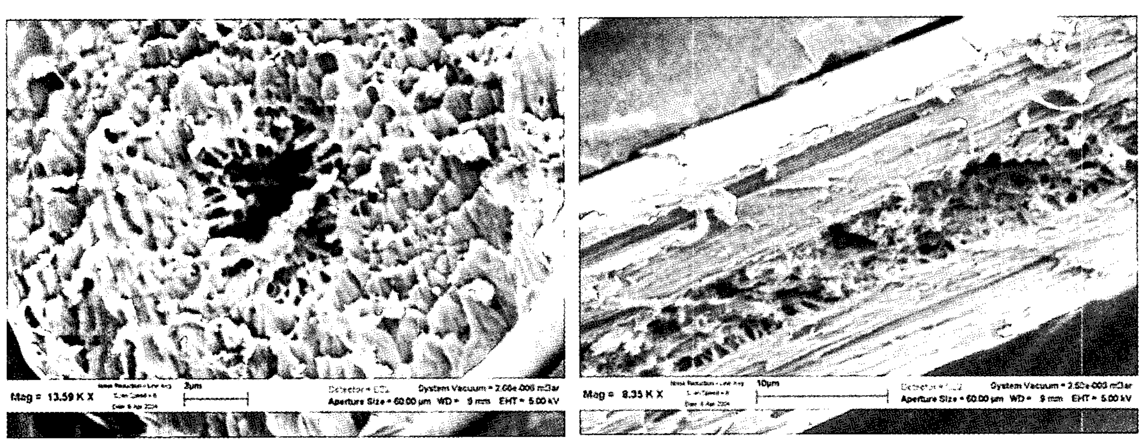
No pigment granules were found in the pure white Suri alpaca fibers in both cross-sectional and longitudinal directions. As shown in Figure 1, the cortical cells of the white Suri fibers are tightly lined up without medullation in the fiber centre. The cuticles closely encase the cortical cells. Similarly, there are no pigment granules in the white Huacaya fibers, but medullas are formed and the cortical cells are not packed as tightly as in the white Suri fibers (Figure 2).

Unlike pure white alpaca fibers, there are numerous pigment granules in the brown and dark-brown colored alpaca fibers, sitting in pockets much like packs of eggs. These granules can be viewed from both longitudinal and cross sectional



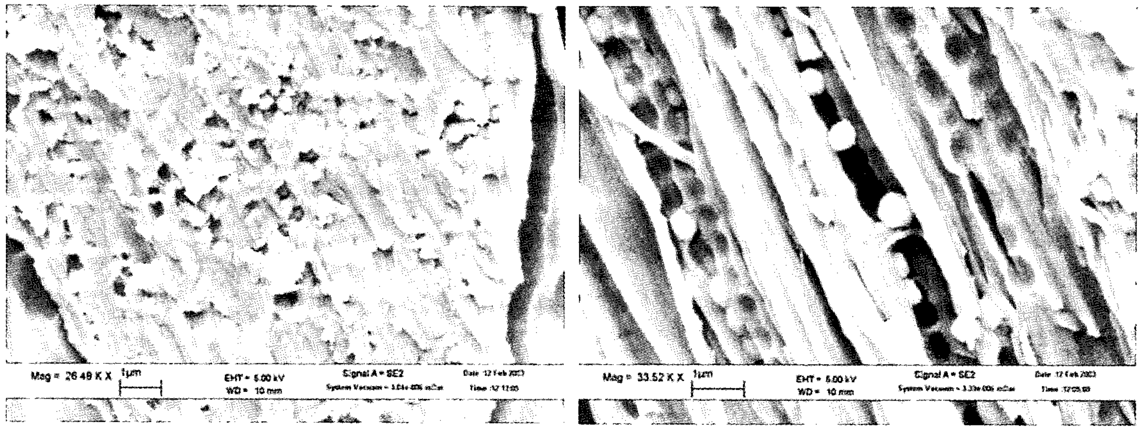
(a) Cross-sectional view (b) Longitudinal view

Figure 1. Views of white Suri alpaca fiber.



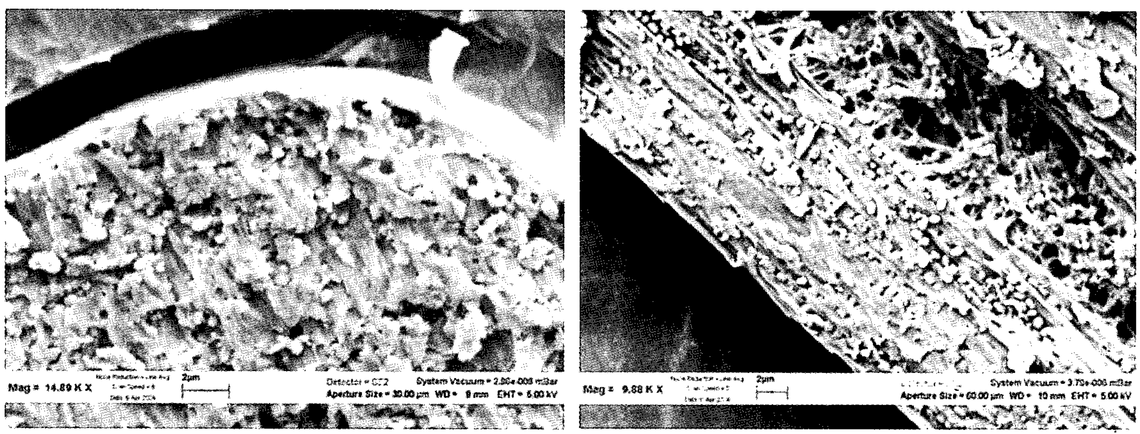
(a) Cross-sectional view (b) Longitudinal view

Figure 2. Views of white Huacaya alpaca fiber.



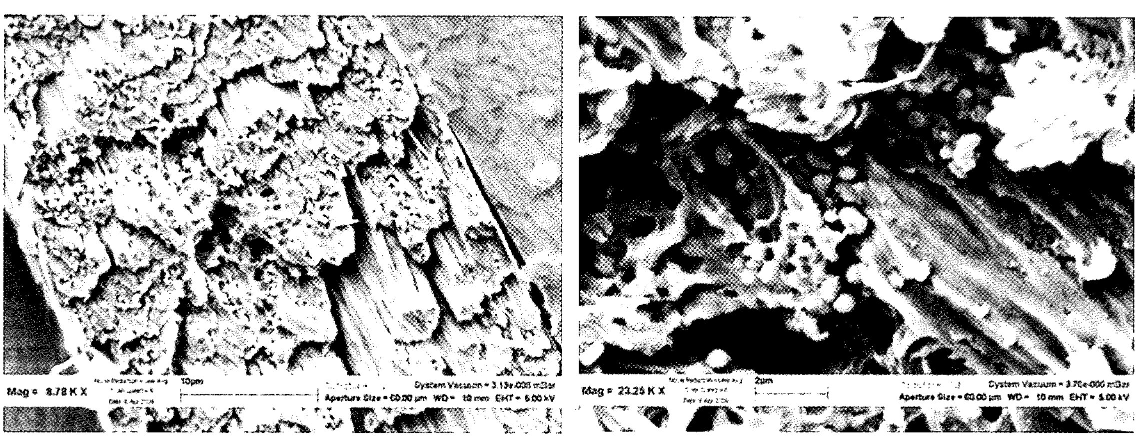
(a) Cross-sectional view (b) Longitudinal view

Figure 3. Views of brown Huacaya alpaca fiber.



(a) Cross-sectional view (b) Longitudinal view

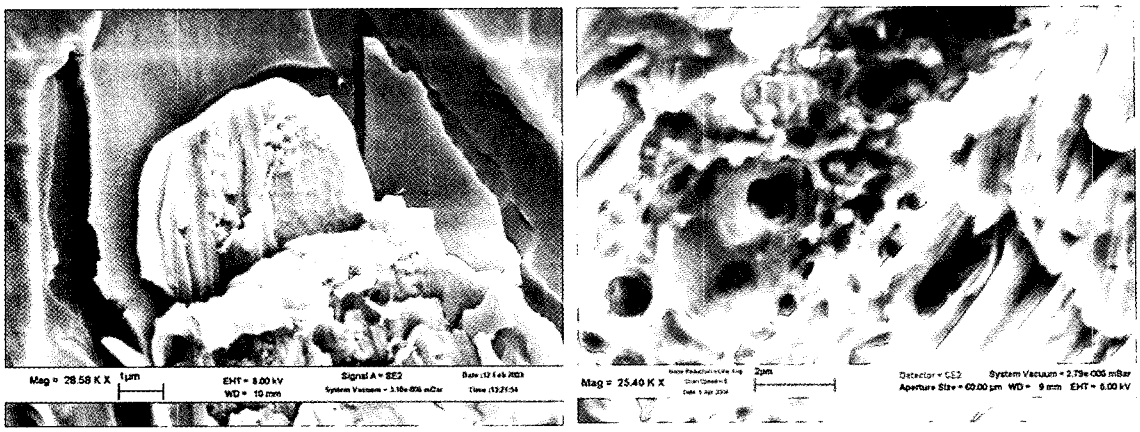
Figure 4. Views of dark brown Huacaya alpaca fiber.



(a) Cortical cell region (b) Medullation regions

Figure 5. Distribution of pigment granules in dark-brown Huacaya alpaca fiber.

SEM photos as indicated in Figures 3 and 4. It is also obvious from these SEM photos that the pigment granules are only loosely attached to the pockets so that they could be dislocated easily when the fibers were cut. The cortical cells of colored



(a) Underneath cuticles (b) Medullation regions

Figure 6. Distribution of pigment granules in brown Huacaya alpaca fiber.

fibers are more loosely bundled than those of pure white alpaca fibers. In addition, there are some crannies between the cuticles and cortical cells due to the existence of the pigment granules. As a result, these loose structures and the crannies may contribute to the high performance of the Huacaya fibers in flexibility, softness, and warmth.

The pigment granules are mainly distributed within the cortical cells, end to end in one to three rows along the cortical cells (Figure 5(a)). In brown fibers, they are mostly lined up in one or two rows (Figure 3(b)), while two to three rows frequently appeared in the dark-brown fibers (Figure 4(b)). The density of the granules in the dark-brown alpaca fibers is much higher than that in the brown fibers. In addition, a layer of the granules could be found just underneath the cuticles (Figure 6(a)), and some presented in the medullated region by sticking with the protein residues (Figure 5(b) and Figure 6(b)). However, the pockets for the pigment granules in the medullated region were not clearly located while doing the SEM observation. It seems that the granules in the medullated region cannot be easily dislocated or do not have complete pockets like in the cortical cell region.

Size of Pigment Granules in Colored Alpaca

As shown in the above figures, the pigment granules in brown and dark-brown alpaca fibers are ball-shaped or egg-shaped. The long and short axes were measured as shown in Table 2. The pigment granules in the brown alpaca fibers are almost round with a 1.32 ratio of the long axis to the short axis, while the egg-shaped granules have a ratio of 1.47 in the dark brown alpaca fibers.

The statistical values in diameter of the granules showed that the size of the granules in the brown fibers is smaller than in the dark-brown fibers. Meanwhile, the size of the granules in the brown fibers is more uniform than in the dark-brown, for the standard deviations of the brown fibers are lower than those of the dark-brown fibers.

Table 2. The size of pigment granules in the brown and dark-brown alpaca fibers

	Statistics	D_max* (μm)	D_min* (μm)	Ratio (D_{max}/D_{min})
Brown Huacaya alpaca	Mean	0.4959	0.3810	1.32
	Mode	0.4100	0.3300	1.24
	Std. deviation	0.1006	0.0762	0.20
	Minimum	0.2900	0.2300	1.01
	Maximum	0.7700	0.6200	2.10
Dark brown Huacaya alpaca	Mean	0.6002	0.4143	1.47
	Mode	0.3800	0.2900	1.37
	Std. deviation	0.1375	0.0879	0.29
	Minimum	0.2900	0.2500	1.00
	Maximum	0.9100	0.7700	2.51

*D_max means maximum diameter and D_min means minimum diameter.

Impact of Bleaching Process on Pigment Granules

The examination by X-ray verified that there were no heavy metal elements existing in the granules, even though the beam had a large interaction volume which possibly included some parts of the cortical cells. The results show that the granules are pure organics, possibly consisting of carbonate, oxygen, sodium, and sulphonium (Figure 7).

For dark colored alpaca fibers, a bleaching process is usually required when dyeing is demanded. The research showed that the alpaca fibers bleached by a mordant hydrogen peroxide system facilitated the dyeing of fibers into attractive colors [1,2,5]. The impact of hydrogen peroxide bleaching on the pigment granules was closely examined in the present research. As indicated in Figure 8, the hydrogen peroxide bleaching process eliminated virtually all pigment granules from the fibers. As a result, all pockets within the fibers were emptied. The elimination of the granules provided the fibers with much larger bases or minute volumes for locating dye molecules

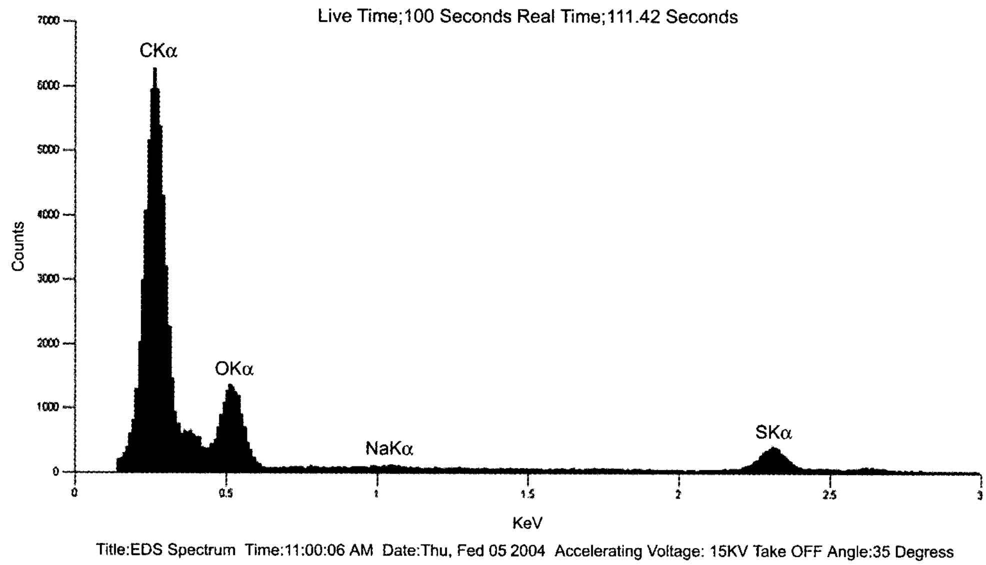
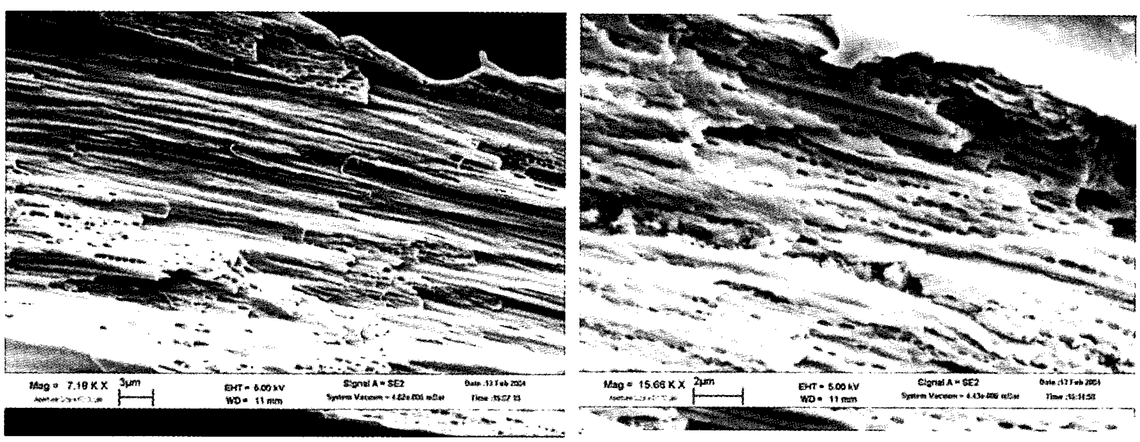


Figure 7. EDS spectrum of the pigment granules in colored alpaca fibers.



(a) Magnification: 7.18KX (b) Magnification: 15.66KX

Figure 8. Elimination of the pigment granules in colored alpaca fibers with bleaching.

so that the bleached fibers could be dyed into more attractive colors. However, the resulting loose structures and cavities may also contribute to the strength loss of the bleached fibers. Further study on fiber mechanical properties in relation to this particular structure would improve our understanding of the properties of alpaca fibers.

Conclusion

The examination of the internal structures of alpaca fibers has shown that the natural pigment granules reside loosely in pockets inside brown and dark-brown colored alpaca fibers. These granules can be dislocated easily when the fibers are cut. The pigment granules are mainly present inside the cortical cells, and the medullation region, as well as underneath the cuticles. The density of the granules in the dark-brown fibers is much higher than that in the brown fibers. However, their size in brown alpaca fibers is smaller and more uniformly round than in dark-brown fibers. The existence of these tiny granules in colored alpaca fibers causes the fiber cortical cells to be packed somewhat loosely, providing many crannies in the fibers which may contribute to the superior flexibility, warmth and softness of fibers.

The measurement of the granules by X-ray shows that there are no heavy metal elements in them. The mordant hydrogen peroxide bleaching employed can eliminate all pigment granules and create many nano-volumes enabling the dyeing of fibers into more attractive colors.

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