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EDITED BY
Seyed Abbas Rafat,
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REVIEWED BY
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Namik Kemal University, Türkiye
Mehmet İhsan Soysal,
Namik Kemal University, Türkiye

*CORRESPONDENCE
Rubén Pinares
ruben.pinares@unsaac.edu.pe

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# Comparing fiber quality characteristics and staple length in Suri and Huacaya alpacas

Rubén Pinares[1]*, Aydee Meza[2], Neyla Crispín[3], Franklin Lozano[4] and Danilo Pezo[5]

[1]Escuela Profesional de Medicina Veterinaria, Universidad Nacional de San Antonio Abad del Cusco, Sicuani, Peru, [2]Centro de Investigación en Camélidos Sudamericanos (CICAS) La Raya, Universidad Nacional de San Antonio Abad del Cusco, Sicuani, Peru, [3]Carrera profesional de Educación Inicial, Instituto de Educación Superior Pedagógico Internacional Elim, Lima, Peru, [4]Facultad de Ingeniería, Universidad Nacional Micaela Bastidas de Apurímac, Abancay, Peru, [5]Facultad de Medicina Veterinaria Instituto Veterinario de Investigaciones Tropicales y de Altura (IVITA - Maranganí), Universidad Nacional Mayor de San Marcos, Lima, Peru

**Introduction:** The textile industry considers alpaca fiber to be a specialty fiber. The aim of this study was to evaluate the influence of color, breed, location, age, and sex of alpacas on fiber quality characteristics and staple length.

**Methods:** Fiber samples were taken from the mid-side of 118 Huacaya and Suri alpacas at two livestock shows (Pitumarca and Maranganí) and at CICAS La Raya (South American Camelid Research Center), which is located in the province of Canchis (Cusco, Peru).

**Results and discussion:** The fiber characteristics and staple length in black alpacas are similar to those of brown alpacas. Huacaya fiber is finer, having a lower mean fiber diameter (MFD), SD, and coefficient of variation of MFD than Suri fiber. Alpacas from the two livestock shows have higher-quality fiber than unselected alpacas raised in CICAS La Raya. Staple length is longer in Suri alpacas than in Huacaya alpacas. Likewise, the staple length is longer in alpacas from Pitumarca, followed by alpacas from Maranganí, and is shorter in alpacas from CICAS La Raya. Young alpacas have a shorter staple length than adults, and it is longer in females than in males. The mean fiber diameter and spinning fineness are strongly correlated with other fiber characteristics in colored alpacas.

**Conclusion:** These black and brown alpacas raised in small herds and judged in two livestock shows produce high-quality fiber at 22 μm for the textile industry.

KEYWORDS

**Fiber color, Suri luster, textile quality, staple length, spinning fineness**

## Introduction

Domestic South American camelids exhibit a diversity of pigmentation patterns. Alpaca fiber is the most valuable product used in the textile industry and has a wide variety of natural colors (Oria et al., 2009; Jost et al., 2020), as is shown by the continuous variation in pigmentation found in Peruvian alpacas (Cruz et al., 2021; Pinares et al., 2021) and through chemical analysis (Wang

et al., 2005; Cransberg et al., 2013). However, the production of colored fiber has decreased over time, directly influenced by the higher price of white fiber, and exacerbated by the erosion of genetic diversity in the Andean camelid population (Antonini and Vinella, 1997; Aragón and Mamani, 2018; Anello et al., 2022).

In alpaca judging shows, two types of fibers are distinguished with differential characteristics: the Huacaya alpacas exhibit higher fiber density with shorter and more crimped fibers, whereas the Suri alpacas exhibit long fibers with curls and luster organized in independent staples, which hang parallel to the body (Lupton and McColl, 2011; Pallotti et al., 2018). The industry and the Peruvian government encouraged the genetic improvement of white alpacas, in order to improve the fiber's characteristics. In contrast, the dark-colored fiber was less valued (Antonini and Vinella, 1997), and, due to the lack of improvement, it maintains a low price (USD1.82/pound) in the textile market (Aragón and Mamani, 2018), whereas white fiber is sold at a high price (USD3.92/pound).

Recently, because of natural and ecological consumer demand, colored fiber has been considered more attractive; therefore, increasing the number of colored alpaca herds has begun through conservation strategies and the formation of Breeder Production Centers (Aragón and Mamani, 2018). The structure and textile qualities of the fiber are commercially important due to their effects on spinning performance and their attributes in final products (handle, comfort, and luxury). In the textile industry, the percentage of medullation and mean fiber diameter (Pinares et al., 2018; Radzik-Rant and Wiercińska, 2021), followed by fiber length, fiber uniformity, comfort factor, color (Simbaina and Raggi, 2019), tenacity, fleece yield, curvature (crimp), and follicle structure, are important.

In this regard, the fiber diameter of Huacaya colored alpacas raised in southern Peru, such as in the Cusco region, especially in the Pitumarca and Maranganí districts, has been improved by selection (Aragón and Mamani, 2018), although in other countries the mean fiber diameter of black Huacaya alpacas (26.62 ± 3.3 µm) has improved only slightly (Simbaina and Raggi, 2019). Dark-brown fiber has a higher fiber diameter than black fiber (27.16 µm), although light-brown fiber is finer, at 23.45 µm (Radzik-Rant and Wiercińska, 2021). In contrast, in one herd of white Suri alpacas, the mean fiber diameter is 20.65 µm (Llactahuamani et al., 2020), but research on fiber quality in colored Suris still remains limited. Therefore, the aim of this research was to evaluate and compare the effect of color, breed, location, age, and sex between colored Huacaya and Suri alpacas on the main characteristics of the fiber.

# Materials and methods

## Animal care and fiber sampling

The study was carried out in the districts of Pitumarca and Maranganí, in the province of Canchis, in the region of Cusco, Peru, between 16 and 24 June 2022 at the XXVI Regional Agricultural Show—Pitumarca 2022 and at the LXX Expo Show Agricultural—Maranganí 2022, and the remaining animals were sampled on 16 June 2022 from the herd of the South American Camelid Research Center (CICAS)—La Raya of the National University of San Antonio Abad del Cusco (Table 1).

The fiber sample collection procedure was approved by the Ethics Committee of the National University of San Antonio Abad del Cusco (CBI–UNSACC) modified by - No. 079-2021-CU-UNSAAC, in accordance with Peruvian National Law No. 30,407 (Animal Protection and Welfare Law). Fiber samples (2 g) were taken from the middle of the left side of the animal (mid-side), behind the third rib, halfway between the back line and the belly line, because it is the most appropriate and representative location (Radzik-Rant et al., 2021) in both Huacaya and Suri alpacas (Figure 1). At both shows, fiber sampling was done at the animal admission stage, prior to judging. Age category was assigned by checking the type and stage of teeth (Table 1), where A = DL (milk teeth, 7–18 months), B = 2D (two teeth, 18 months–2 years), C = 4D (four teeth, 2–3 years), and D = BL (full mouth, ≥ 3 years).

## Measurements of fiber property

The OFDA 2000 device was calibrated using a standard wool top, following the IWTO-47 procedures (IWTO-47, 2007), under standard laboratory conditions at 20 ± 2°C temperature and 65 ± 5% relative humidity, following IWTO-52 procedures (IWTO-52, 2006). The fiber textile characteristics MFD, maximum diameter (max. D), minimum diameter (min. D), and the difference in fiber diameter (DFD), standard deviation of MFD (SD), coefficient of variation of MFD (CV), spinning fineness (SF), percentage of fibers < 30 µm or comfort factor (CF), mean fiber curvature (CU), and staple length (SL) were measured using the Optical-based Fiber Diameter Analyzer (OFDA 2000) at the South American Camelid Research Center (CICAS), Fiber Laboratory of National University of San Antonio Abad del Cusco.

TABLE 1 Number (*n*) of alpacas sampled according to color, breed, age, and sex from Pitumarca, Maranganí, and CICAS La Raya (Cusco, Peru).

| Location | Color | | | Breed | | Age category | | | | Sex | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BA | DB | LB | H | S | DL | 2D | 4D | BL | M | F | |
| **Pitumarca** | 19 | 13 | 12 | 25 | 19 | 09 | 15 | 06 | 14 | 23 | 21 | 44 |
| **Maranganí** | 10 | 13 | 18 | 21 | 20 | 11 | 11 | 08 | 11 | 13 | 28 | 41 |
| **CICAS La Raya** | 06 | 15 | 12 | 22 | 11 | 02 | 26 | 00 | 05 | 27 | 06 | 33 |
| **Total** | 35 | 41 | 42 | 68 | 50 | 22 | 52 | 14 | 30 | 63 | 55 | 118 |

Color: black (BA), dark brown (DB), light brown (LB); Breed: Huacaya (H), Suri (S); Age: milk teeth (DL), two teeth (2D), four teeth (4D), full mouth (BL); Sex: male (M), female (F).


FIGURE 1
Color of alpaca fibers sampled. Suri (left) and Huacaya (right).

Raw staples homogeneously distributed in the sample holder were measured by optical scanning. The OFDA 2000 device is a video microscope set above a moving sample of fibers. The instrument magnifies and captures images (2000 individual fibers) using a video camera and then identifies and measures each fiber. An OFDA output includes the diameter along the fiber, from the base to the tip, also recording minimum and maximum diameters. The CF is the estimate of the percentage of fibers < 30 μm and the prickling factor is calculated as 100 – CF. The spinning fineness, based on the MFD and its coefficient of variation, was calculated using an OFDA 2000 device as: $SF = 0.881 \times MFD \times \sqrt{(1 + 5\ (CV/100)^2)}$.

## Statistical analysis

The analysis of variance (ANOVA type II tests) was done in the context of a completely randomized design for each fiber property, based on the linear model $Y_{ijklmn} = \mu + C_i + B_j + L_k + A_l + S_m + (C^*B)_{ij} + (C^*L)_{ik} + (C^*A)_{il} + (C^*S)_{im} + (B^*L)_{jk} + (B^*A)_{il} + (B^*S)_{jm} + (L^*A)_{kl} + (L^*S)_{km} + (A^*S)_{lm} + e_{ijklmn}$ that considers the effect of the main factors of color ($C_i$), breed ($B_j$), location ($L_k$), age ($A_l$), sex ($S_m$), and their double interactions (10 combinations of of two factors): $(C^*B)_{ij} + (C^*L)_{ik} + (C^*A)_{il} + (C^*S)_{im} + (B^*L)_{jk} + (B^*A)_{il} + (B^*S)_{jm} + (L^*A)_{kl} + (L^*S)_{km} + (A^*S)_{lm}$. The levels of the five main factors are detailed in parenthesis: color (three levels: light brown, dark brown, and black), breed (two levels: Huacaya and Suri), location (three levels: Pitumarca, Maranganí, and CICAS La Raya), age (four levels: A, DL; B, 2D; C, 4D; and D, BL), and sex (two levels: male and female).

A Tukey test ($\alpha = 0.05$) was used for the multiple comparisons of means for fiber properties. Pearson's correlation coefficient was calculated for fiber characteristics. The statistical analysis was performed on R software, version 4.1.1 (R Core Team, 2021), using the library (Rcmdr), packages: RcmdrMisc, car, carData, sandwich, effects, and applying the aov command and glht function for ANOVA and Tukey test, respectively. The graphic of the mean fiber diameter distribution by breed (Huacaya, $n = 68$; Suri, $n = 50$; total, $n = 118$ alpacas) was plotted using a density plot function in R software.

# Results

## Effect of color, breed and location on fiber quality and staple length

In Huacaya and Suri alpacas (Figure 2), the mean fiber diameter (MFD) is not influenced by color ($p > 0.05$; Table 2). Huacaya alpacas have significantly finer fiber ($p < 0.05$; Figure 3), with a significantly lower SD of MFD ($p < 0.001$) and coefficient of variation of MFD than Suri alpacas ($p < 0.05$). Breed, location, and age (Table 2) have a significant influence on MFD. Alpacas from both livestock shows produce higher-quality fiber, with lower MFD than the unselected alpacas from CICAS La Raya (Figure 4).

The minimum and maximum fiber diameters in alpacas from Pitumarca and Maranganí are similar but are lower than those obtained in alpacas from CICAS La Raya ($p < 0.05$). The difference in diameters along the staple length is greater in Suri than in Huacaya alpacas ($p < 0.05$), but it is more variable in Suri alpacas due to the greater staple length.

The alpacas from both livestock shows have 90% of fibers < 30 μm (comfort), with a spinning fineness of 22 μm; these animals have higher fiber comfort and reduced spinning fineness than those of the CICAS La Raya alpacas ($p < 0.05$). Females have a significantly higher comfort factor ($p < 0.05$) and better ($p < 0.05$) spinning fineness than males; Huacayas have a significantly better

FIGURE 2
Comparison of visual fiber characteristics in Huacaya and Suri alpacas from Peru (left) and Australia (right).

spinning fineness than Suris ($p < 0.01$). The mean fiber curvature (Table 2) is significantly greater in Huacayas ($p < 0.001$) than in Suris, but is not influenced by other factors ($p > 0.05$) such as fiber color, location, age, and sex.

Staple length is significantly different between breed, location, age, and sex (Table 2). Suri alpaca mean staples reach a length of ≥ 120 mm in adults, whereas the Huacaya staples are smaller (≤ 70 mm; Figure 5). Alpacas from Pitumarca have longer staples, followed by alpacas from Maranganí, and alpacas from CICAS La Raya have a shorter staple length than both. As expected, young alpacas have a shorter staple length than adults. In addition, the staple length is longer in females than in males ($p < 0.05$) (Table 2).

No significant double interactions of the five factors analyzed (color, breed, location, age, and sex) were observed in the fiber characteristics, except there was a significant interaction between breed and age on the mean staple length ± standard error. The Huacaya and Suri alpacas (at the milk teeth age stage) have similar staple lengths (Figure 5). MFD has a high and significant positive correlation (0.99; $p < 0.001$) with the spinning fineness (Table 3) and with the SD of MFD (0.90; $p < 0.001$). The SD of MFD correlates positively with SF (0.94) and negatively with CF (–0.89). A negative correlation between MFD and CU (–0.46) indicates that, as fibers get thicker, the mean curvature decreases, or vice versa. Staple length (SL) has a positive correlation with DFD, CV of MFD, and CU; however, SL is not correlated with MFD, SD, and SF.

TABLE 2 Effect of color, breed, location, age, and sex on the quality and staple length in alpacas.

| | #n | MFD (µm) | SD of MFD (µm) | CV of MFD (%) | CF (%) | SF (µm) | CU (°/mm) | SL (mm) | Min. D (µm) | Max. D (µm) | DFD (µm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Color | | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| Black | 35 | 23.82 | 5.29 | 22.24 | 86.33 | 23.46 | 31.36 | 89.71 | 21.83 | 26.97 | 5.14 |
| Dark brown | 41 | 24.30 | 5.34 | 21.89 | 82.47 | 23.88 | 31.11 | 90.61 | 21.93 | 27.43 | 5.50 |
| Light brown | 42 | 23.01 | 5.09 | 22.03 | 87.36 | 22.64 | 36.51 | 87.86 | 21.10 | 25.97 | 4.87 |
| Breed | | * | *** | * | ns | ** | *** | *** | ns | * | * |
| Huacaya | 68 | 22.95 | 4.88 | 21.27 | 87.69 | 22.41 | 45.14 | 68.16 | 21.03 | 25.68 | 4.65 |
| Suri | 50 | 24.71 | 5.72 | 23.10 | 82.19 | 24.53 | 16.75 | 118.20 | 22.39 | 28.26 | 5.87 |
| Location | | *** | *** | ns | ** | *** | ns | *** | *** | ** | ns |
| Pitumarca | 44 | 22.48[a] | 4.98[a] | 22.14 | 90.37[b] | 22.13[a] | 34.06 | 108.49[c] | 20.48[a] | 25.72[a] | 5.24 |
| Maranganí | 41 | 22.28[a] | 4.95[a] | 22.17 | 89.72[b] | 21.94[a] | 32.69 | 90.49[b] | 20.27[a] | 25.36[a] | 5.09 |
| La Raya | 33 | 27.08[b] | 5.93[b] | 21.76 | 73.25[a] | 26.60[b] | 32.36 | 62.58[a] | 24.77[b] | 29.94[b] | 5.16 |
| Age | | ns | ns | ns | ns | ns | ns | * | ns | ns | ns |

*(Continued)*

TABLE 2 Continued

| | #n | MFD (μm) | SD of MFD (μm) | CV of MFD (%) | CF (%) | SF (μm) | CU (°/mm) | SL (mm) | Min. D (μm) | Max. D (μm) | DFD (μm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A: DL | 22 | 22.23 | 5.08 | 22.71 | 90.73 | 22.02 | 28.11 | 83.64$^{ab}$ | 20.05 | 25.49 | 5.44 |
| B: 2D | 52 | 23.79 | 5.27 | 22.04 | 84.09 | 23.42 | 34.42 | 80.67$^{a}$ | 21.65 | 26.84 | 5.19 |
| C: 4D | 14 | 22.96 | 5.08 | 22.03 | 88.61 | 22.59 | 37.81 | 90.71$^{ab}$ | 21.21 | 26.16 | 4.96 |
| D: BL | 30 | 24.95 | 5.37 | 21.57 | 82.10 | 24.42 | 32.30 | 108.00$^{b}$ | 22.85 | 27.88 | 5.03 |
| Sex | | ns | * | ns | * | * | ns | * | ns | ns | ns |
| Male | 63 | 24.86 | 5.54 | 22.26 | 81.19 | 24.51 | 30.53 | 81.51 | 22.74 | 27.88 | 5.16 |
| Female | 55 | 22.36 | 4.88 | 21.80 | 90.13 | 21.94 | 36.05 | 98.36 | 20.31 | 25.50 | 5.20 |

#n, number of fiber samples; ns, non-significant; max. D, maximum diameter; min. D, minimum diameter MFD, mean fiber diameter; SD, standard deviation; CV, coefficient of variation; SF, spinning fineness; CF, comfort factor or percentage of fibers < 30 μm; CU, mean curvature; SL, staple length; DFD, difference of fiber diameter. p-values: ***p < 0.001; **p < 0.01; *p < 0.05.

## Discussion

Most fiber textile quality properties are not significantly different between black, dark-brown, and light-brown alpacas. This may be influenced by selection for fiber fineness in colored alpacas, as in white alpaca herds. However, in Poland, Radzik-Rant and Wiercińska (2021) indicated a difference in MFD between dark (27.16 μm) as compared with light (23.45 μm) alpaca fibers, which was also linked to a higher extent of medullation observed in dark alpaca fibers. Lupton et al. (2006), in Huacaya alpacas from the USA, as well as Machaca et al. (2017) and Oria et al. (2009), studying alpacas from different regions of Peru, found that light-brown fibers had lower MFD than dark ones. Likewise, this pattern was observed in Bolivian Huacaya alpacas (Aruquipa, 2015). Therefore, instrument measurement of color could help to produce uniform alpaca color lines, if, in fact, this is desirable in a breeding program (Lupton et al., 2006).

Colored Huacayas have finer fibers with lower SD and CV of MFD than colored Suris, similar to Huacayas compared with Suris, as reported by Cervantes et al. (2010) and Llactahuamani et al. (2020). Huacaya fleece also differs from Suri by the greater mean fiber curvature (crimp): it stands out in the finest Huacayas (Lupton et al., 2006; McGregor, 2006; Lupton and McColl, 2011). Hence, the structure and organization of cortical cells may provide a key to fiber curvature differentiating; they are also believed to play an important role in the crimp development of Huacaya alpaca fibers. Suri fibers do not display the traditional ortho- and para-bicortical structure of crimped Huacaya fibers (Shim, 2003).

The maximum fiber diameter (28.26 μm) is greater in Suris than in Huacayas (25.68 μm). In contrast, Olarte (2022) reported a maximum fiber diameter of 23.12 μm in young Huacaya mothers in lactation physiological states and pregnancy, as compared with a maximum fiber diameter of 28.73 μm in pregnant adult mothers. Fiber diameter difference and fiber annual growth rate are influenced indirectly by rainfall and grassland availability (Quispe et al., 2021a; Olarte, 2022). In addition, the difference in fiber diameter is related to the synthesis of amino acids, especially keratin proteins (Hunter, 2020).

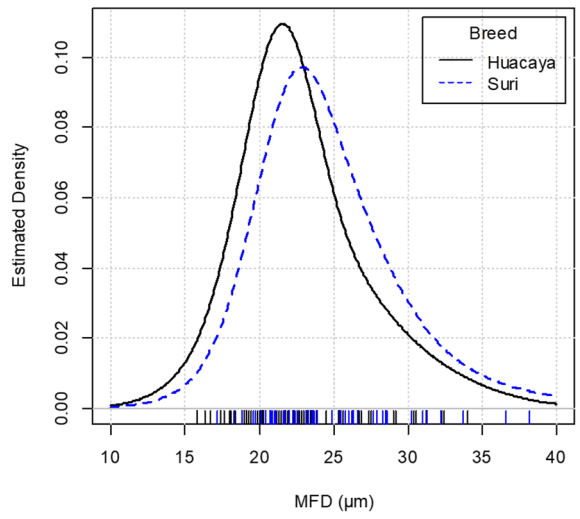


FIGURE 3
Distribution of mean fiber diameter in Huacaya and Suri colored alpacas (*x*-axis). The *y*-axis label refers to frequency.

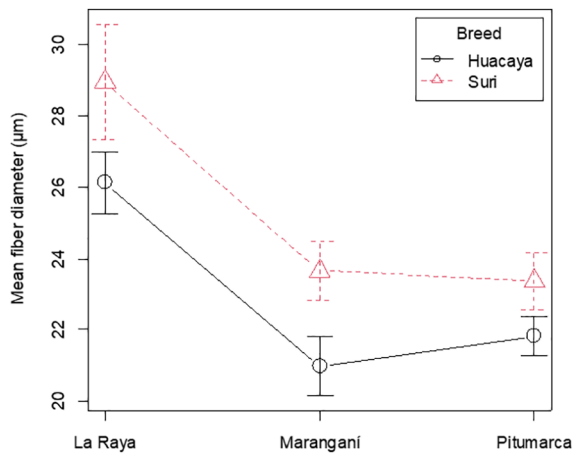


FIGURE 4
Comparison of alpaca mean fiber diameter by location and breed. Mean ± standard error of mean fiber diameter.

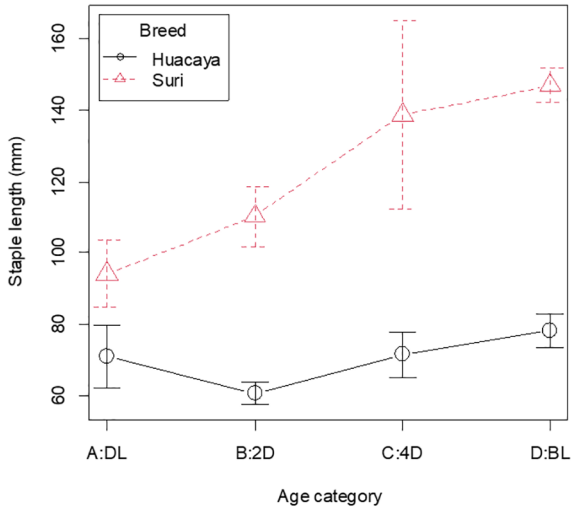


FIGURE 5
Interaction between breed and age on the mean staple length ± standard error.

As Suri fleece luster stands out, subjective determination depends on the expertise of the judge. Lupton and McColl (2011) indicated a small negative correlation between MFD and subjectively assessed luster scores; they also found a small positive correlation between MFD and objectively measured luster values. However, there is a strong negative correlation (–0.94) between luster instrumental measurement and $\log_{10}$ of luminance (Lupton and McColl, 2011).

The fiber quality and staple length differ between alpacas from livestock shows and CICAS La Raya. Unfortunately, the samples obtained from CICAS La Raya alpacas do not include colored alpacas selected for improvement (blue eyes, spotting, and other genetic defects were observed). Therefore, the MFD was 27.08 µm.

Alpaca breeders and show judges spend considerable time and effort subjectively assessing the relative merits of alpacas of different colors (Lupton et al., 2006). Fleece evaluation in shows is subjective, according to the standards of the Huacaya and Suri alpacas (Supreme Decree No. 013-2011-AG): to choose those animals that present the most outstanding phenotypic characteristics

TABLE 3 Pearson's correlation coefficients of the main characteristics of colored alpaca fibers.

| | CU | CV | Max. D | MFD | Min. D | DFD | SD | SF | SL |
|---|---|---|---|---|---|---|---|---|---|
| **CF** | 0.40<br>*< 0.0001* | –0.23<br>*0.0117* | –0.93<br>*< 0.0001* | –0.95<br>*< 0.0001* | –0.90<br>*< 0.0001* | –0.44<br>*< 0.0001* | –0.89<br>*< 0.0001* | –0.96<br>*< 0.0001* | 0.04<br>*> 0.05* |
| **CU** | 1 | –0.46<br>*< 0.0001* | –0.51<br>*< 0.0001* | –0.46<br>*< 0.0001* | –0.43<br>*< 0.0001* | –0.37<br>*< 0.0001* | –0.56<br>*< 0.0001* | –0.49<br>*< 0.0001* | –0.56<br>*< 0.0001* |
| **CV** | | 1 | 0.28<br>*0.0023* | 0.18<br>*0.0490* | 0.11<br>*> 0.05* | 0.46<br>*< 0.0001* | 0.57<br>*< 0.0001* | 0.28<br>*0.0024* | 0.30<br>*0.0008* |
| **Max. D** | | | 1 | 0.97<br>*< 0.0001* | 0.92<br>*< 0.0001* | 0.58<br>*< 0.0001* | 0.92<br>*< 0.0001* | 0.98<br>*< 0.0001* | 0.10<br>*> 0.05* |
| **MFD** | | | | 1 | 0.97<br>*< 0.0001* | 0.41<br>*< 0.0001* | 0.90<br>*< 0.0001* | 0.99<br>*< 0.0001* | –0.01<br>*> 0.05* |
| **Min. D** | | | | | 1 | 0.21<br>*0.0217* | 0.84<br>*< 0.0001* | 0.96<br>*< 0.0001* | –0.04<br>*> 0.05* |
| **DFD** | | | | | | 1 | 0.54<br>*< 0.0001* | 0.45<br>*< 0.0001* | 0.33<br>*0.0003* |
| **SD** | | | | | | | 1 | 0.94 | 0.11<br>*> 0.05* |
| **SF** | | | | | | | | 1 | 0.02<br>*> 0.05* |

Max. D, maximum diameter; min. D, minimum diameter; DFD, difference of fiber diameter; MFD, mean fiber diameter; SD, standard deviation; CV, coefficient of variation; SF, spinning fineness; CF, comfort factor; CU, mean curvature; SL, staple length. In each row the value of the correlation coefficient is indicated, and below it, in italics, is the p-value.

related to productivity (often the ideal animal is not found). The sex has no effect on MFD, in agreement with Lupton et al. (2006) and Quispe et al. (2021b). In Ecuador, Simbaina and Raggi (2019) and Simbaina-Solano et al. (2016) found no statistical differences between sexes, but in Polish alpacas, Radzik-Rant et al. (2021) reported greater MFD in males (27.15 μm) than in females (23.46 μm).

Alpacas at the two shows had lower MFD (22 μm), similar to the 21.84 μm reported by Quispe et al. (2021b) in Huacayas from the LVIII Livestock Show of Puno, Peru (FEGASUR). Young black and brown Huacayas (category A) have finer fiber (20.73 μm) than adult Huacayas at 24.92 μm (category D). Age is the factor that most affects fiber diameter. Lupton et al. (2006) indicated that the MFD increases in old Huacaya alpacas: from 20.00 μm in young alpacas to 22.95 μm in adult alpacas (Quispe et al., 2021b). Likewise, Crossley et al. (2014) reported an MFD of 21.61 μm in juvenile alpacas (1–2 years) and of 23.47 μm in adults (3–6 years). Gutiérrez et al. (2011) found a positive correlation between MFD at birth and fiber growth; the authors recommended selecting those animals that maintain a fine fiber throughout their lives.

In this study, the alpacas did not have the same length of time for fiber growth (some alpacas at the show were recently shorn); however, the alpacas from CICAS La Raya are shorn only once a year, and for this reason, the mean staple length of 62.58 mm indicates annual fiber growth. Suris have an annual growth of between 120 and 200 mm; at the shows, some are unshorn and others are half-shorn. According to the Peruvian Technical Standard, a staple length of 65 mm is adequate for the combing system in the extra-fine category and 70 mm for other alpaca categories (NTP, 2019). In white, light-fawn, and light-brown Polish Huacaya alpacas (3–5 years old) the staple length is high at 12.8 ± 3.5 cm, where shearing is not annual (Radzik-Rant et al., 2021).

Machaca et al. (2017) reported differences in fiber length by location between herds from neighboring communities in alpacas from the Apurimac region, Peru. The difference in staple length may be due to external factors such as climate, feeding, and shearing management; fiber growth depends on physiology, protein metabolism, shearing frequency, and genetic factors. Pallotti et al. (2018) associated the differences in fiber growth with fibroblast growth factor 5 (FGF5). Females have a longer staple than males; however, in one study, males had a greater fiber length than females (Lupton et al., 2006). According to recent studies, sex does not influence the staple length (Paucar-Chanca et al., 2019; Quispe et al., 2021a); the difference might be caused by genetic influences (Anello et al., 2022), different shearing practices, high selection pressure in males, or physiological state in females.

MFD and spinning fineness have a positive correlation. Pinares and Yauri (2019) indicated a perfect relationship between these properties in vicuña fibers. MFD has a direct influence on yarn properties and processing performance; it is correlated with the other textile characteristics of the fiber, as discovered by Machaca et al. (2017) and Wuliji (2019). The positive correlation between SD and SF at 0.94 is 0.88 in vicuñas, whereas the negative correlation between SD and CF, at –0.89, is the same in both species (Pinares and Machaca, 2022).

There is a negative correlation between CF and MFD (–0.95), such as –0.94 and –0.93 reported by Paucar-Chanca et al. (2019) in alpacas from Peru and by Simbaina and Raggi (2019) in alpacas from Ecuador, respectively. Likewise, in the white finest fibers the comfort increases or vice versa. Staple length is negatively correlated in these alpacas, with a mean curvature at –0.56, superior to the figure of –0.28 found by Wuliji (2019). There is a positive correlation between CF and mean curvature (0.40) such as 0.45 (Wuliji, 2019) and 0.62 (Machaca et al., 2017); when fiber comfort increases, the mean curvature increases in thick fibers or vice versa, and both properties decrease in finest fibers.

## Conclusions

Black and brown alpacas in the Cusco region (Pitumarca and Maranganí districts) produce fibers with similar textile characteristics and staple lengths. Suri alpacas have good luster and spin and longer staple lengths, although their fiber has a lower quality (MFD of 24.71 μm) than Huacaya alpacas (MFD of 22.95 μm). Furthermore, there is no significant variation in CF between Huacaya and Suri alpacas.

The best black and brown alpacas judged at livestock shows are those with the smallest MFD (22 μm) and uniformity of the fiber diameter on the fleece, with a staple length greater than 7.5 cm, as required for the textile industry. In these black and brown colors there is a significant positive or negative correlation ($p < 0.01$) among all fiber characteristics, except CV with min. D; and there are no significant associations between the SL and each of the following fiber characteristics: CF, MFD, min. D, max. D, SD, and SF.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The animal study was reviewed and approved by No 079-2021-CU-UNSAAC. Written informed consent was obtained from the owners for the participation of their animals in this study.

## Author contributions

RP, AM, and DP undertook the fiber sampling and laboratory analysis. RP contributed to conception and design of the study, organized the database, and performed the statistical analysis. AM, NC, FL, and DP contributed to the original draft preparation. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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