

Staple strength is associated with textile characteristics of fibre in black and brown alpacas

La resistencia a la tracción de la mecha está asociada con las características textiles de la fibra en alpacas negras y marrones

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ABSTRACT

The aim of this study was to determine the correlation between the staple strength and the textile characteristics of black and brown fibres, as well as to evaluate the influence of colour, breed, location, age, and sex of alpaca on the staple strength properties. Staple strength was measured with the Staple Length & Strength instrument. Fibre characteristics were measured using an Optical-based Fibre Diameter Analyzer (OFDA 2000). Data did not show a normal distribution, as verified by the Shapiro-Wilk normality test. Spearman's rank correlation coefficients between staple strength and fibre textile characteristics were calculated. The influence of colour, breed, location, age, and sex of alpacas on the staple strength properties were analysed separately by the Kruskal-Wallis rank sum test ($\alpha=0.05$). The highest correlation was observed between peak force position and staple length ($r_s = 0.99$), as well as significant positive correlations for staple strength with peak force ($r_s = 0.53$), with fibre curvature ($r_s = 0.42$), and with comfort factor ($r_s = 0.20$). However, there were negative correlations for staple strength with spinning fineness ($r_s = -0.20$) and standard deviation of mean fibre diameter ($r_s = -0.23$). The fibre colour and the sex of the alpaca did not influence on the staple strength and peak force; location did not influence

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on the staple strength ($p>0.05$). However, the age category and the breed influenced the staple strength and staple length ($p<0.05$). Staple strength increased with age, ranging from 16.75 to 20.10 N/ktex for young animals (milk teeth and 2-teeth categories) and 38 N/ktex for 4-teeth animals. Suri fibre is longer and has a lower staple strength (13.4 N/ktex) compared to Huacaya fibre (29.5 N/ktex). In conclusion, the favourable negative correlations between textile and physical properties would allow a reduction in the standard deviation of MFD and spinning fineness, while improving staple strength in black and brown alpacas.

Keywords: alpaca industry, fleece colour, fibre quality, staple length, stable strength properties

RESUMEN

Este estudio tuvo como objetivo determinar la correlación entre la resistencia a la tracción de la mecha y las características textiles de la fibra negra y marrón, así como evaluar la influencia del color, raza, ubicación, edad y sexo de la alpaca sobre las propiedades de resistencia a la tracción. La resistencia de la mecha se midió con el instrumento Staple Length & Strength. Las características de la fibra se midieron utilizando un analizador óptico de diámetro de fibra (OFDA 2000). Los datos no mostraron una distribución normal según la verificación de la prueba de normalidad de Shapiro-Wilk. Se calcularon los coeficientes de correlación de rangos de Spearman entre la resistencia a la tracción y las características textiles de la fibra. La influencia del color, raza, ubicación, edad y sexo de las alpacas sobre las propiedades de resistencia de la mecha se analizó por separado mediante la prueba de suma de rangos de Kruskal-Wallis ($\alpha=0.05$). La correlación más alta se observó entre la posición de fuerza máxima y la longitud de la fibra ($r_s = 0.99$); asimismo hubo correlaciones positivas significativas para la resistencia de la mecha con la fuerza máxima ($r_s = 0.53$), con la curvatura de la fibra ($r_s = 0.42$) y con el factor de confort ($r_s = 0.20$). Sin embargo, hubo correlaciones negativas para la resistencia a la tracción con la finura al hilado ($r_s = -0.20$) y con la desviación estándar del diámetro medio de la fibra ($r_s = -0.23$). El color de la fibra y el sexo de la alpaca no influyeron en la resistencia a la tracción de la mecha ni en la fuerza máxima; la ubicación no influyó en la resistencia de la mecha ($p>0.05$). Sin embargo, la categoría de edad y la raza influyeron sobre la resistencia de la mecha y la longitud ($p<0.05$). La resistencia a la tracción de la mecha aumentó con la edad, de 16.75 a 20.10 N/ktex para jóvenes (categorías de dientes de leche y 2 dientes) y 38 N/ktex para 4 dientes. La fibra de Suri es más larga y una tiene menor resistencia a la tracción (13.4 N/ktex) en comparación con la de Huacaya (29.5 N/ktex). En conclusión, las correlaciones negativas favorables entre las propiedades textiles y físicas permitirían una reducción de la desviación estándar de DMF y la finura al hilado, mejorando al mismo tiempo la resistencia a la tracción de la mecha en alpacas negras y marrones.

Palabras clave: industria de la alpaca, color del vellón, calidad de fibra, longitud de mecha, propiedades de resistencia a la tracción

INTRODUCTION

Andean camelids show variations in diameter along the staple length (fibre diameter profile, FDP) during the annual or

seasonal fibre growth, due to nutritional availability in dry and rainy seasons, physiological conditions (Mayhua *et al.*, 2012; Pinares and Yauri, 2019; Quispe *et al.*, 2021; Olarte, 2022) and other factors associate to stress (Elvira and Jacob, 2004). The variability

of alpaca colour remains in the high Andean regions of Peru (Oria *et al.*, 2009; Pinares *et al.*, 2021, 2023), that is a potential for crafts and the textile industry. Despite the above, there are few studies in Peruvian alpacas of dark colours, regarding the textile characteristics as fibre diameter and medullation (Lozano *et al.*, 2023; Pinares *et al.*, 2023) and very limited studies for alpaca and Ch'aku llama regarding the physical or mechanical properties as staple strength (Llactahuamani *et al.*, 2020; Quispe-Ccasa *et al.*, 2020).

The mean and standard deviation of fibre diameter, medullation, fibre curvature, staple length and staple strength are the main properties that influence on industrial processing and garment production (Villarroel, 1963; Wuliji *et al.*, 2000; Lupton *et al.*, 2006; McGregor, 2006; Simbaina y Raggi, 2019; Radzik-Rant and Wiercińska, 2021; Pinares *et al.*, 2023). The most valued attribute of alpaca fibre is handled soft and very warm, thanks to fragmented, discontinuous and continuous medulla, within the fibres that trap air (Czaplicki, 2012; Pinares *et al.*, 2018, 2019). Suri fleece is also valued because it is lustrous (Lupton and McColl, 2011). Those who wear alpaca garments choose them because of their thermal qualities, physical and mechanical properties (strength) of the fibre, as well as some other attributes such as their impermeability and anti-inflammability, lower fibre density or specific weight (Czaplicki, 2012). Therefore, a smaller mean fibre diameter, but with greater mean staple strength $\pm$ SD (50.16 ± 21.40 N/ktex) is required for the textile industry (Lupton *et al.*, 2006).

Staple strength is the force required to break a staple (the maximum break force for staple per unit of average linear density), and it is measured in Newton per kilotex (Wuliji *et al.*, 2000; McGregor, 2006; Lupton *et al.*, 2006; Scobie *et al.*, 2015; Llactahuamani *et al.*, 2020; Gonzalez *et al.*, 2020). The breaking point is associated with the fibre minimum diameter profile; therefore, the thinner section of fibre breaks faster. Staple

strength could be tested empirically by stretching individual strands between the fingers and applying a tensile force until they break, but this is very subjective (Elvira and Jacob, 2004). The objective of this study was to determine the correlations between the staple strength and the textile characteristics of black and brown alpaca fibre, as well as to evaluate the influence of colour, breed, location, age and sex on the staple strength properties.

MATERIALS AND METHODS

Animal Care and Fibre Sampling

The study was carried out in Pitumarca and Maranganí districts in the province of Canchis, Cusco, Peru, in June 2022 at the XXVI Regional Agricultural Show – Pitumarca, the LXX Expo Show Agricultural - Maranganí, and the South American Camelid Research Centre (CICAS «La Raya») of the Universidad Nacional San Antonio Abad del Cusco (UNSAAC). All procedures were 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 N.º 30407 (Animal Protection and Welfare Law).

A total of 102 fibre samples (5 g) were randomly taken from mid-side (Table 1), centred over the tenth rib, midway between the back line and the belly line (Radzik-Rant *et al.*, 2021). In both shows, coloured fibre sampling was carried out at the animal admission stage, prior to judging. Age category was assigned based on teeth, 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). Fibre colour was classified in black (BA), dark brown (DB) and light brown (LB), as described by Pinares *et al.* (2023) using the fleece colour chart of Australian Alpaca Association (2012).

Table 1. Number of alpacas sampled according to colour, breed, age and sex from Pitumarca, Marangani and CICAS La Raya (Cusco, Peru)

Location	Colour			Breed		Age category				Sex		Total
	BA	DB	LB	H	S	DL	2D	4D	BL	M	F	
Pitumarca	17	11	08	19	17	05	13	05	13	18	18	36
Marangani	10	10	16	20	16	08	10	08	10	09	27	36
CICAS La Raya	05	14	11	19	11	02	23	00	05	24	06	30
Total	32	35	35	58	44	15	46	13	28	51	51	102

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

Table 2. Spearman's correlation coefficients between the staple strength properties measured by Staple Length & Strength and the fibre textile characteristics measured by OFDA 2000 in coloured Huacaya and Suri alpacas

	Staple strength	Peak force	Staple length
Difference of fibre diameter	-0.19	-0.17	0.26**
Maximum diameter	-0.21*	0.10	-0.01
Minimum diameter	-0.16	0.21*	-0.12
Comfort factor	0.20*	-0.15	0.08
Fibre curvature	0.42***	0.36***	-0.24*
Mean fibre diameter (MFD)	-0.19	0.16	-0.09
MFD standard deviation	-0.23*	0.06	-0.07
MFD coefficient of variation	0.19	-0.20*	0.05
Spinning fineness	-0.20*	0.14	-0.08
Peak force	0.53***	1.00	-0.06
Peak force position	0.10	0.02	0.99***
Staple strength	1.0	-	-0.21*

Significant correlations are shown with asterisk (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$)

Measurements of Fibre Property

Samples with >300 fibres and length >60 mm were considered for sampling. The staple strength (N/ktex), peak force (N), peak force position (mm) and staple length (mm) were analysed using the Staple Length & Strength model AJM-SL&S 07 (Interactive Wool Group, Australia), previously calibrated according to manual instructions. Scobie *et al.* (2015) indicated that the force needed is normalized using linear density units in grams per meter (ktex) and the amount of force needed to break a staple is measured in Newtons (N).

The fibre textile characteristics were previously measured by Pinares *et al.* (2023) in the same animals using the Optical-based Fibre Diameter Analyzer (OFDA 2000). For this study, the maximum diameter (μm), minimum diameter (μm), difference of fibre diameter (μm), staple length (mm), comfort factor (%), fibre curvature ($^\circ/\text{mm}$), mean fibre diameter (MFD, μm), MFD standard deviation (μm), MFD coefficient of variation (%) and spinning fineness (μm) have been considered. Since staple length were measured with two instruments, Spearman's correlation for staple length measured by

Table 3. Median for staple strength, peak force and staple length by colour, breed, location, age and sex of alpacas

	n	Staple strength (N/ktex)	Peak force (N)	Peak force position (mm)	Staple length (mm)
Colour		<i>0.60</i>	<i>0.65</i>	<i>0.58</i>	<i>0.63</i>
Black	32	17.7 ^a	78.0 ^a	115 ^a	91.5 ^a
Dark brown	35	22.1 ^a	86.5 ^a	116 ^a	93.0 ^a
Light brown	35	19.8 ^a	91.5 ^a	107 ^a	87.5 ^a
Breed		<i><0.001</i>	<i><0.001</i>	<i>0.01</i>	<i><0.001</i>
Huacaya	58	29.5 ^a	111 ^a	118 ^a	84.0 ^b
Suri	44	13.4 ^b	63.0 ^b	107 ^b	98.0 ^a
Location		<i>0.12</i>	<i>0.04</i>	<i><0.001</i>	<i><0.001</i>
Pitumarca	36	27.8 ^a	88.5 ^{ab}	144 ^a	124 ^a
Marangani	36	18.5 ^a	74.5 ^b	109 ^b	89.0 ^b
La Raya	30	16.8 ^a	101 ^a	92.0 ^b	71.5 ^c
Age category		<i>0.02</i>	<i>0.01</i>	<i>0.04</i>	<i>0.05</i>
A:DL	15	20.1 ^b	59.0 ^b	109 ^{ab}	90.0 ^{ab}
B:2D	46	16.8 ^b	84.0 ^{ab}	101 ^b	78.0 ^b
C:4D	13	38.0 ^a	124 ^a	117 ^{ab}	93.0 ^{ab}
D:BL	28	20.3 ^b	88.0 ^{ab}	121 ^a	96.0 ^a
Sex		<i>0.31</i>	<i>0.55</i>	<i>0.07</i>	<i>0.07</i>
Male	51	18.0 ^a	88.0 ^a	109 ^a	87.0 ^a
Female	51	23.2 ^a	82.0 ^a	117 ^a	93.0 ^a
General	102	20.1	88.0	114.0	91.0
Minimum	102	4.90	16.0	73.0	49.0
Maximum	102	86.7	273	235	213

OFDA 2000 and by Staple Length & Strength was high ($r_s = 0.80$) with $p < 0.01$. Therefore, values obtained by Staple Length & Strength was considered for this study. Fibre measurements were carried out at the Fibre Laboratory of South American Camelid Research Centre (CICAS «La Raya»), UNSAAC.

Statistical Analysis

Data were verified through the Shapiro-Wilk normality test. Due to the staple strength properties not showing a normal distribution, Spearman's rank correlation coefficients were calculated among staple strength properties and fibre textile characteristics. Likewise, non-parametric statistics [Kruskal-Wallis rank sum test ($\alpha = 0.05$)] was used for

median comparisons. The influence of colour, breed, location, age, and sex of animals on the staple strength properties were analysed separately by pairwise comparison using the Dunn Test ($\alpha = 0.05$). The statistical analyses were performed on R software, v. 4.1.1 (R Core Team, 2023).

RESULTS

Correlation between staple strength and fibre characteristics

The fibre textile characteristics were strongly correlated with the staple strength in dark-coloured alpacas (between -0.23 and 0.53). Likewise, some of these characteristics

correlated with the peak force and staple length (between -0.24 and 0.36). Thus, a high correlation ($r_s = 0.99$) was obtained between staple length and peak force position (Table 2).

Factors affecting the staple strength

The colour of the fleece, the location and the sex of the alpaca did not influence the staple strength ($p > 0.05$). In the case of Huacaya alpacas, the staple strength and the peak force were higher than those of Suri alpacas. Likewise, staple strength increases with age, between 16.75 and 20.10 N/ktex for young (milk teeth and 2-teeth categories) and 38 N/ktex for 4-teeth category. However, the staple length in Huacaya was shorter compared to Suri (Table 3).

DISCUSSION

Positive correlations were found among the staple strength with the comfort factor ($r_s = 0.20$) and with the peak force ($r_s = 0.53$). Fibre curvature was positively correlated with staple strength ($r_s = 0.42$) and peak force ($r_s = 0.36$). A positive correlation ($r = 0.30$) was found between fibre curvature and staple strength in Huacaya and Suri alpacas by Llactahuamani *et al.* (2020), but a negative correlation ($r = -0.26$) was reported by Lupton *et al.* (2006) in Huacaya. The fibre curvature was negatively correlated with staple length ($r_s = -0.24$), in agreement with -0.28 reported by Wuliji (2019).

There was a negative correlation between the staple strength with the fibre maximum diameter profile ($r_s = -0.21$) and with the MFD standard deviation ($r_s = -0.23$). In this regard, Quispe *et al.* (2021) indicate that the fibre diameter profile for annual growth (seasonal variation) is approximated by the maximum, minimum diameter along the staple and the difference in these diameters. Therefore, the positive correlation of 0.24 ($p < 0.05$) between peak force position and difference of fibre diameters, is relevant to improve at the same time staple strength and fibre diameter profile.

The negative correlation ($r_s = -0.21$) between staple strength and length means that the shorter the length, the greater the staple strength. This finding is corroborated with previous studies by Wuliji *et al.* (2000), McGregor (2006) and Lupton *et al.* (2006). Although this study did not find an association between MFD and staple strength ($r_s = -0.19$), previous reports in Huacaya alpaca with high MFD $\geq 28 \mu\text{m}$ showed significant positive correlations ($r > 0.34$; Wuliji *et al.*, 2000; Lupton *et al.*, 2006; McGregor, 2006). This would affect the mechanical and textile performance of the alpaca industry. No relationship was found between comfort factor and staple length similar to previous studies by Pinares *et al.* (2023); however, Simbaina and Raggi (2019) reported a negative correlation ($r_s = -0.32$).

The alpaca fleece colour did not influence the staple strength and peak force of the fibre ($p > 0.05$), similar to the results of Lupton *et al.* (2006) and Wuliji *et al.* (2000). However, Wuliji *et al.* (2000) found that white crias (31.7 N/ktex) had greater staple strength compared to dark and light brown ones (26.2 N/ktex), but similar to black ones (29.2 N/ktex).

In contrast, for Huacaya alpacas in USA, Lupton *et al.* (2006) reported a mean $\pm$ SD (50.16 ± 21.40 N/ktex), with minimums and maximums of 5 and 138 N/ktex, respectively. Likewise, in Australian alpacas, McGregor (2006) reported 81 and 68 N/ktex for Huacaya and Suri, respectively ($p < 0.05$). These high values of staple strength in foreign-alpaca breeding are in part related to their high MFD ($\geq 28 \mu\text{m}$; McGregor, 2006; Wuliji *et al.*, 2000; Lupton *et al.*, 2006).

In Ocongate (Cusco), Llactahuamani *et al.* (2020) indicated that Suri alpacas had less staple strength (60.11 N/ktex) than Huacaya (81.66 N/ktex). The median differences found in our research between Huacaya (29.5 N/ktex) and Suri (13.4 N/ktex) could be related with differential distribution of internal cortical cells (Shim, 2003; Holt, 2007), as the bilateral

distribution of cortical cells can differentiate the fibre curvature in Huacaya. In Suri fibres, the ortho and para cortex cells are not distributed bilaterally (Shim, 2003; Holt, 2007). On the other hand, the greater staple strength in Huacaya was attributed to its more ordered structure (higher crystallinity) in the alpaca helices making up the microfibrils, as revealed by X-ray diffraction (Hunter, 2020).

Staple length in Huacaya was shorter compared to Suri, due to the differentiated fibre growth between these breeds; thus, explaining in part by regulation of *FGF5* gene, it can in turn arrest the follicle development during the anagen phase or retard its progression (Pallotti *et al.*, 2018).

Staple strength is affected by age; thus, values of 31.8 ± 2.1 N/ktex (mean $\pm$ standard error) have been reported in adult Huacaya alpacas taken to New Zealand (Wuliji *et al.*, 2000), similarly to the present results (38.0 ± 2.1 N/ktex) in 2-3 years old alpacas. Nevertheless, Wuliji *et al.* (2000) reported higher values in crias (28.4 ± 1.9 N/ktex) than 7-18-month-old alpacas in the present study (20.10 ± 4.6 N/ktex).

From the point of view of textile processing, Elvira and Jacob (2004) indicate that values higher than 30 N/ktex are appropriate. Therefore, Huacaya alpaca fibre seems to have a good staple strength (Wuliji *et al.*, 2000; Lupton *et al.*, 2006; McGregor, 2006; Llactahuamani *et al.*, 2020).

None of the staple strength properties were influenced by sex (Table 3). Males and females showed medians of 18.0 and 23.2 N/ktex, respectively ($p > 0.05$). The results were consistent with 32.1 and 31.4 N/ktex reported by Wuliji *et al.* (2000) in males and females, respectively. Similarly, Llactahuamani *et al.* (2020) reported that sex did not influence on the staple strength. However, Lupton *et al.* (2006) found that males (44.5 N/ktex) produced stronger fibres than females (38.7 N/ktex). Likewise, Quispe-

Ccasa *et al.* (2020) found higher staple strength and MFD in males (69.11 N/ktex, 27.31 μ m) than in females (57.39 N/ktex, 23.63 μ m) in Ch'aku llama.

CONCLUSIONS

- Staple strength, fibre curvature and comfort increase due to the positive correlation of staple strength with peak force, with fibre curvature, and with comfort factor.
- The colour, location and sex of the alpaca did not influence on the staple strength ($p > 0.05$).
- As age increases, staple strength and length increases, partly due to the larger size of fibre.
- Although Suri has a longer staple length, it has a lower staple strength than Huacaya due to the different internal structure of the fibres between the two breeds.

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