Research Article

Fibre Characteristics of Huacaya and Suri Alpaca from a Rural Alianza Livestock Farm of Peru

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Abstract | The aim of this study was to determine the characteristics of Huacaya and Suri alpaca fiber: mean fiber diameter (MFD), standard deviation of fiber diameter (SDFD), coefficient of variation (CV), comfort factor (CF), and curvature index (CI) based on breed, sex and age. A total of 454 fiber samples were collected from Huacaya and Suri alpacas aged Milk-teeth, 2-teeth, 4-teeth and Full-mouth, which were analyzed at the Fiber Laboratory of the District Municipality of Corani, using OFDA 2000 equipment. Huacaya alpacas exhibited smaller fiber diameters by sex (Male: 19.99 µm and females: 20.66 µm) compared to Suri alpacas (Male: 23.13µm and females: 23.13 µm). In terms of comfort and curvature index variables, both breeds displayed similar trends, but Huacaya had better values than Suri.

Keywords | Alpaca, Textile characteristics, Fiber, Huacaya, Suri

Received | July 06, 2024; **Accepted** | January 14, 2024; **Published** | February 01, 2025
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Citation | Carlo-Lozada LA, Quispe-Huanca MP, Perez-Guerra UH, Manrique-Quispe YP, Canaza-Cayo AW, Jara-Vargas CW, Rodríguez-Huanca FH (2025). Fibre characteristics of huacaya and suri alpaca from a rural alianza livestock farm of Peru. J. Anim. Health Prod. 13(1): 23-28.
DOI | https://dx.doi.org/10.17582/journal.jahp/2025/13.1.23.28
ISSN (Online) | 2308-2801

INTRODUCTION

Ninety-seven percent of the alpaca population is located in the Peruvian Andes, above 3500 meters above sea level. The animals are under the care of small and medium-sized breeders (Quispe *et al.*, 2016). Two breeds of alpacas make up the 3.6 million animals in Peru: Huacaya (79%) and Suri (12%) (CENAGRO, 2013). Peru is the main producer of alpaca fiber globally, with an annual production of 3,399 tons. 90% of the national production is aimed at the international market and represents an average of 1.35% of exports (FAO, 2005; Lupton *et al.*, 2006). The Puno region has the largest alpaca population in the country (39.6% of the population) (Quispe *et al.*, 2016).

It is estimated that over 300,000 families depend directly or indirectly on alpaca fiber or meat production under challenging geographic conditions and a variable climate. Recently, there has been growing interest in South American camelid production due to the global demand for fiber,

particularly because alpaca fiber is competitive with finer fibers (Quispe *et al*., 2013; Machaca *et al*., 2017).

The textile industry views alpaca fiber as a premium material, and the garments made from it are considered luxury items (Wang *et al*., 2003a) due to their textile properties such as fiber diameter (Roque-Gonzales and Valdez, 2018). The aim of this study was to evaluate the textile characteristics of Huacaya and Suri alpaca fiber based on breed, sex and age.

MATERIALS AND METHODS

Study Location and Animal Selection

The study was conducted in the Antacalla and Conchatanca regions of the Rural Alianza livestock farm, situated between the provinces of Melgar and Carabaya in the department of Puno. The altitude ranged from 4000 to 4400 m, with the following geographical coordinates: Latitude: -14.0683, Longitude: -70.4314, Latitude: 14° 4' 6'" South, Longitude: 70° 25' 53'" West. The climate in this area is characterized as rainy and semi-frigid, with low humidity in winter. The maximum temperature is approximately 12°C year-round, while the minimum temperatures vary from 2°C in the summer to -6.5°C in the winter. The annual rainfall accumulation is 636 mm, with the highest monthly rainfall occurring in January at 138.4 mm (SENAMHI, 2021).

When collecting fiber samples, factors such as breed, sex, and age were recorded. 10 grams of fiber was collected from the mid-rib area (McGregor, 2012) and stored in a polyethylene bag labeled with information regarding breed, sex, age, ear tag number, origin, and color. A total of 454 samples were collected from Huacaya and Suri breeds.

Fiber Analysis

The samples underwent analysis using the OFDA 2000 (Optical Fiber Diameter Analysis) (Marler *et al*., 2002; Wood, 2003) at the Fiber Laboratory of the District Municipality of Corani. The analysis included mean fiber diameter, standard deviation, coefficient of variation, comfort factor, and curvature index. The study followed a completely randomized design with a factorial arrangement of 2 (sex) x 4 (age). Data analysis was carried out using SAS Software version 9.2 (SAS 2008), and the comparison of means was conducted using Tukey's Significance test with $\alpha = 0.05$.

RESULTS AND DISCUSSION

Fiber Characteristics in Huacaya Alpacas

The fiber characteristics of the Huacaya alpaca show no significant variation between sex, except for MFD, which is higher in females than males. There are variations in MFD, SDFD, CV, and CF based on age, but no differences were observed for CI (Table 1).

Table 1: Fiber characteristics in Huacaya alpacas by sex and age.

Traits	Factor	Levels	n	Mean	SD	CV
MFD (µm)	Sex	Male	119	19.99^{b}	0.29	16.08
		Female	139	20.66^{a}	0.29	16.49
	Age	Milk-teeth	70	17.64^{d}	0.23	10.88
		2-teeth	72	19.12^{c}	0.21	9.49
		4-teeth	49	21.92^{b}	0.41	13.07
		Full-mouth	67	23.37^{a}	0.37	13.05
SDFD (µm)	Sex	Male	119	4.21^{a}	0.69	16.48
		Female	139	4.26^{a}	0.68	15.90
	Age	Milk-teeth	70	3.68^{d}	0.49	13.20
		2-teeth	72	4.09^{c}	0.48	11.63
		4-teeth	49	4.48^{b}	0.62	13.94
		Full-mouth	67	4.80^{a}	0.57	11.96
CV (%)	Sex	Male	119	21.17^{a}	1.79	8.45
		Female	139	20.73^{a}	1.89	9.14
	Age	Milk-teeth	70	20.83^{b}	1.71	8.20
		2-teeth	72	21.53^{a}	1.80	8.35
		4-teeth	49	20.57^{b}	1.78	8.65
		Full-mouth	67	20.67^{b}	2.01	9.71
CF (%)	Sex	Male	119	95.65^{a}	6.55	6.84
		Female	139	94.50^{a}	8.96	9.48
	Age	Milk-teeth	70	99.15^{a}	1.76	1.77
		2-teeth	72	98.04^{a}	2.13	2.18
		4-teeth	49	93.12^{b}	6.48	6.96
		Full-mouth	67	88.91^{c}	11.76	13.23
CI (°/mm)	Sex	Male	119	49.08^{a}	7.56	15.40
		Female	139	47.36^{b}	6.80	14.37
	Age	Milk-teeth	70	48.47^{a}	8.52	17.57
		2-teeth	72	48.44^{a}	6.41	13.23
		4-teeth	49	49.16^{a}	6.87	13.97
		Full-mouth	67	46.78^{a}	6.68	14.27

Means with different superscripts within same columns and factor differ significantly ($p<0.05$); **MFD:** Mean fiber diameter; **SDFD:** Standard deviation of fiber diameter; **CV:** Coefficient of variation; **CF:** Comfort factor; **CI:** Curvature index.

The results by Machaca *et al*. (2017) in Cotaruse show higher values by sex, with 23.79 µm and 22.79 µm in male and female alpacas respectively. Similarly, Roque and Valdez (2018) recorded 23.23 µm and 23.48 µm, and Paucar-Chanca *et al*. (2019) reported 23.54 µm and 22.95 µm. Vásquez *et al*. (2015) also reported similar averages of 19.60 µm and 20.10 µm in males and females. However, Quispe *et al*. (2021) reported lower averages than this study (19.59

µm and 19.27 µm, male and female, respectively). These differences may be attributed to the effect of wet and/or dry puna and the degree of selection practiced in each research area.

MFD increases as the age of the animal increases. Machaca *et al.* (2017) reported higher values according to age, with 21.61 µm, 22.22 µm, 23.87 µm, 24.32 µm in milk-teeth, 2-teeth, 4-teeth and full-mouth animals respectively. Similarly, Gandarillas *et al.* (2022) recorded 20.34 µm, 20.63 µm in milk tooth and 2-teeth. Vásquez *et al.* (2015) reported similar averages of 17.8 µm, 19.7 µm in milk tooth and 2-teeth animals, while in 4-teeth and full-mouth, lower values of 20.7 µm and 22.1 µm were observed. Similarly, Gandarillas *et al.* (2022) reported values of 20.89 and 21.77 µm. The standard deviation of fiber diameter in Huacaya alpacas does not show variation by sex. By age, differences were observed; animals of Milk-teeth had lower diameter (3.68 µm).

The results of the current study of standard deviation by sex are lower than those reported by Gandarillas *et al.* (2022), who found 5.19 µm and 5.21 µm in males and females. Quispe *et al.* (2021) also obtained similar results of 4.73 µm and 4.71 µm; Paucar-Chanca *et al.* (2019) recorded 4.5 µm and 4.2 µm in male and female alpacas, respectively.

Gandarillas *et al.* (2022) reported higher values based on age, with 5.26 µm, 5.22 µm, 5.14 µm, and 5.30 µm in alpacas with milk-teeth, 2-teeth, 4-teeth, and full-mouth respectively; Quispe *et al.* (2021) found 4.62 µm in milk-teeth. Quispe *et al.* (2021) also reported 4.80 µm, 4.90 µm, and 4.79 µm in animals with 2-teeth, 4-teeth, and full-mouth.

The fiber coefficient of variation in Huacaya alpacas does not vary by sex but by age. Animals having 2-teeth had higher average compared to other ages (milk-teeth, 4-teeth, and full-mouth).

The results from this study on the coefficient of variation by sex are lower than those reported by Quispe *et al.* (2021) and Machaca *et al.* (2017). Vásquez *et al.* (2015) also found similar results with 21.2% and 21.3%. Paucar-Chanca *et al.* (2019) reported lower averages than this study with 19.57% and 18.69%; Machaca *et al.* (2021) with 18.95% and 19.14% in male and female alpacas, respectively.

Machaca *et al.* (2017) showed higher values compared to those in this study by 23.68%, 23.04%, 21.46%, and 22.22% in animals with milk-teeth, 2-teeth, 4-teeth, and full-mouth; Quispe *et al.* (2021) recorded 24.25%, 24.55%, 24.06%, and 22.96% in milk-teeth, 2-teeth, 4-teeth, and full-mouth respectively. Similar results were also reported by Vasquez *et al.* (2015) with values of 21.3%, 21.2%, 21.1%, and 21.3%.

The fiber comfort factor in Huacaya alpacas did not exhibit variation by sex, or by milk-teeth or 2-teeth ages. But differences were observed when compared with 4-teeth and full-mouth alpacas.

Our results regarding sex are lower than those documented by Quispe *et al.* (2021) at 96.34% and 97.01%. The findings of this study are higher than those obtained by Roque and Ormachea (2018) with lower values of 92.87% and 92.83%; Machaca *et al.* (2017) with 87.41% and 91.23%; Paucar-Chanca *et al.* (2019) with 90.38% and 92.27%; and Gandarillas *et al.* (2022) with 93.93% and 93.23%. Similar values were reported in the study by Quispe *et al.* (2021) at 95.98% and 94.24% for males and females. The similarity in values is attributed to the similar management practices in the extensive breeding system.

Quispe *et al.* (2021) achieved higher values compared to those obtained based on age, with 95.88% and 95.26% in 4-teeth and full-mouth alpacas. Gandarillas *et al.* (2022) reported 91.97% in full-mouth. Machaca *et al.* (2017) documented lower values of 92.38%, 92.02%, 88.13%, and 86.45% in milk-teeth, 2-teeth, 4-teeth, and full-mouth alpacas. Quispe *et al.* (2021) found 97.18% and 96.87% in milk-teeth and 2-teeth. Gandarillas *et al.* (2022) observed 94.41% and 93.22% in milk-teeth and 2-teeth. Similar results were seen by Gandarillas *et al.* (2022) with 93.46% in 4-teeth alpacas. These variations indicate a decrease in fiber curvature with age, suggesting that the most suitable fiber for the textile industry comes from milk-teeth and 2-teeth alpacas.

The fiber curvature index in Huacaya alpacas exhibited differences based on sex, while no significant variations were noted by age.

The findings presented by Quispe *et al.* (2021) showed higher values in males than females. Conversely, Machaca *et al.* (2021) obtained lower values in males than females. Roque and Ormachea (2018) reported 35.23 °/mm and 34.80 °/mm; Machaca *et al.* (2017) found 33.76 °/mm and 38.23 °/mm; Gandarillas *et al.* (2022) observed 34.66 °/mm and 34.88 °/mm; Vásquez *et al.* (2015) documented 36.9 °/mm and 37.1 °/mm; Quispe, *et al.* (2021) recorded 37.57 °/mm and 37.92 °/mm; Ormachea *et al.* (2015) noted 42.26 °/mm and 42.34 °/mm.

The results presented by Quispe *et al.* (2021) were higher than those obtained in this study based on age. Machaca *et al.* (2017) reported lower averages of 33.35°/mm, 40.19 °/mm, 38.60 °/mm, and 35.66 °/mm; Gandarillas *et al.* (2022) found 31.48 °/mm, 36.50 °/mm, 36.91°/mm, and 34.60 °/mm; Vásquez *et al.* (2015) observed 35.8 °/mm,

36.9 °/mm, 37.6°/mm, 38.2 °/mm. These differences could be attributed to differences in management practices in the production process.

Fiber Characteristics of Suri Alpacas

The fiber characteristics of Suri alpacas show no significant variation based on sex, except for MFD, which is higher in females and lower in males. There are variations in MFD, SDFD, CV, and CF, based on age, but no differences were observed for CI (Table 2).

Table 2: Fiber characteristics in Suri alpacas by sex and age.

Traits	Factor	Levels	n	Mean	SD	CV
MFD (µm)	Sex	Male	91	23.13[a]	0.36	14.91
		Female	105	23.21[a]	0.31	13.52
	Age	Milk-teeth	47	20.30[c]	0.32	10.67
		2-teeth	39	23.13[b]	0.44	12.01
		4-teeth	46	24.52[a]	0.43	11.82
		Full-mouth	64	24.35[a]	0.40	13.17
SDFD (µm)	Sex	Male	91	5.03[a]	0.82	16.21
		Female	105	4.96[a]	0.70	14.12
	Age	Milk-teeth	47	4.62[b]	0.63	13.64
		2-teeth	39	4.99[a]	0.74	14.80
		4-teeth	46	5.24[a]	0.86	16.42
		Full-mouth	64	5.11[a]	0.68	13.24
CV (%)	Sex	Male	91	21.81[a]	1.99	9.14
		Female	105	21.44[a]	2.02	9.42
	Age	Milk-teeth	47	22.80[a]	1.74	7.62
		2-teeth	39	21.64[b]	1.47	6.78
		4-teeth	46	21.19[b]	2.31	10.92
		Full-mouth	64	21.03[b]	1.91	9.09
CF (%)	Sex	Male	91	89.39[a]	9.95	11.13
		Female	105	89.52[a]	9.18	10.26
	Age	Milk-teeth	47	95.72[a]	4.90	5.12
		2-teeth	39	90.69[b]	8.45	9.32
		4-teeth	46	86.03[c]	9.73	11.31
		Full-mouth	64	86.58[c]	10.26	11.85
CI (°/mm)	Sex	Male	91	17.25[a]	3.49	20.22
		Female	105	17.21[a]	3.34	19.41
	Age	Milk-teeth	47	19.76[a]	3.04	15.37
		2-teeth	39	16.93[b]	2.31	13.64
		4-teeth	46	15.77[b]	3.17	20.13
		Full-mouth	64	16.60[b]	3.45	20.77

Means with different superscripts within same columns and factor differ significantly ($p<0.05$); **MFD:** Mean fiber diameter; **SDFD:** Standard deviation of fiber diameter; **CV:** Coefficient of variation; **CF:** Comfort factor; **CI:** Curvature index.

The fiber diameter in Suri alpacas does not vary between males and females (23.13±0.36 µm and 23.21 µm). Age shows variation in diameter, since the older the alpaca is, the higher the diameter increases. The absence of variation in MFD by sex, agrees with several authors: Quispe (2018), Flores (2009), Calcina and Mamani (2014), Huanchi (2018), Tapia (2018) and Garcia (2019). The results found from the present study are similar to that reported by Calcina and Mamani (2014); Tapia (2018); Checalla *et al.* (2021).

Conversely, Malaga *et al.* (2022) reported lower values by age. These differences are due to the age of the alpacas. As the age of the animal increases, the effect of wet and/or dry puna, and the degree of selection practiced in each breeding environment changes. The standard deviation of fiber diameter in Suri alpacas between males and females did not show significant differences ($p>0.05$). While age did show variation, where milk-teeth animals had a lower average (4.62) than 2-teeth, 4-teeth, and full-mouth (4.99, 5.24, and 5.11, respectively) ($p<0.05$).

The CV of fiber diameter in Suri alpacas between sex was not significantly different ($p>0.05$). However, there is variability in age, with milk-teeth animals having a higher percentage (22.80%) than 2-teeth, 4-teeth, and full-mouth ($p<0.05$).

The CV observed by sex in this study was lower than previous reports in Malaga *et al.* (2022), Australia Aylan-Parker and McGregor (2002), Huaman (2023), Pumaleque (2020) and Velarde (2021). However, the CV was similar to the findings of Llactahuamani *et al.* (2020) in Cusco, Garcia (2019) and Quispe (2018) in Bolivia.

The CV based on age in this research was lower than the values reported by Garcia (2019) in Puno, Huaman (2023), Quispe *et al.* (2021), Malaga *et al.* (2022), Velarde (2021), Aylan-Parker and McGregor (2002) in Australia, and Lupton *et al.* (2006) in the United States; suggesting that fibers from Rural Alianza livestock were more uniform than those in the referenced studies. Additionally, the results were similar to the findings of Garcia (2019) and Llactahuamani *et al.* (2020).

The mean fiber curvature index (CI) in Suri alpacas was comparable between males (89.39%) and females (89.52%). However, the CI decreased with age in Huacaya alpacas ($p<0.05$). The CI values in this study were similar to those reported by Malaga *et al.* (2022), Quispe *et al.* (2021), Garcia (2019) and Lupton *et al.* (2006).

The fiber curvature index in Suri alpacas does not vary by sex ($p>0.05$). Conversely, there is variation by age, with milk-teeth animals exhibiting a higher index (19.76°/mm) compared to other age groups. There is a decrease in the

index as age progresses ($p<0.05$).

Correlation Between Fiber Characteristics

Pearson's correlation coefficients obtained between fiber traits are shown in Table 3. All correlation estimates were significant, except CV-CF. The MFD had a significant and high correlation with SDFD, However, MFD had a significant and negative correlation with CV, CF and CI. The correlation estimates obtained in this study are in agreement with other studies (Llactahuamani *et al*., 2020; Malaga *et al*., 2022; Zuñiga *et al*., 2022). These results suggest that selection toward a decrease in MFD might contribute to an increase in CF.

Table 3: Pearson's correlation coefficient estimates among FW and fiber characteristics in the alpaca from the Rural Alianza livestock farm.

	MFD	SDFD	CV	CF	CI
MFD		0.85	-0.17	-0.88	-0.53
SDFD	0.001		0.35	-0.78	-0.57
CV	0.001	0.001		0.08	-0.11
CF	0.001	0.001	0.082		0.43
CI	0.001	0.001	0.015	0.001	

MFD: Mean fiber diameter; **SDFD:** Standard deviation of fiber diameter; **CV:** Coefficient of variation; **CF:** Comfort factor; **CI:** Curvature index. Correlations above the diagonal and probability below the diagonal.

CONCLUSIONS AND RECOMMENDATIONS

The mean fiber diameter, comfort factor, and curvature index of Huacaya and Suri alpacas exhibit similar trends. Younger alpacas have better fiber diameters, while comfort decreases with age. The curvature index is only significant by sex in Huacaya alpacas and by age for Suri alpacas. In terms of breed, Huacayas outperform Suri alpacas in all characteristics, indicating better management and genetic improvement due to their larger population.

ACKNOWLEDGEMENTS

The authors are grateful for valuable assistance of all staff Rural Alianza livestock farm, situated between the provinces of Melgar and Carabaya in the department of Puno - Perú.

NOVELTY STATEMENTS

The study of Fiber Characteristics of Huacaya and Suri Alpaca from a Rural Alianza Livestock Farm of Peru shows the fiber characteristics of Suris and Huacaya alpacas according to age and sex.

AUTHOR'S CONTRIBUTIONS

Luis Alberto Carlo Lozada; Investigation, Writing, Data analysis, Marvin Pablo Quispe Huanca, Uri Harold Perez-Guerra, Yan Pierr Manrique Quispe; Statistical analysis, Methodology, Writing of Original draft., Ali William Canaza-Cayo, Carlos Wilkerson Jara Vargas; Editing, Review, Francisco Halley Rodríguez-Huanca; Formal analysis, Writing of Original draft.

Conflict of Interest

The authors have declared no conflict of interest.

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