SHORT COMMUNICATION

https://doi.org/10.21708/avb.2023.18.4.12526

Reproductive status and age effects on Huacaya alpaca fiber medullation

Estado reprodutivo e efeitos da idade na medulação da fibra de alpacas Huacaya

Alfonso Cordero Fernandez[1], Manuel Castrejon Valdez[1], Melanio Jurado Escobar[1], Paul Mayhua Mendoza[1], José Luis Contreras Paco[1], Jordan Ninahuanca[2]*

ABSTRACT: This study delved into the impact of environmental factors on the medullation of fibers (continuous (C), interrupted (I), fragmented (F), and non-medullated (NM)) in white female Huacaya alpacas. Utilizing records and fiber samples from 185 alpacas at the Research and Development Center for South American Camelids Lachocc, National University of Huancavelica (Peru), statistical analyses were executed employing the least squares method for unequal numbers in subclasses. The age of the alpacas exhibited a statistically significant influence on the type of fiber medullation, with the exception of fragmented medullated fiber. The regression equations generated facilitate predictive modeling for continuous, interrupted, and non-medullated medullae. Mean values (%) for continuous medullae were observed as 27.45, 27.98, 28.03; interrupted medullae as 33.15, 34.13, 35.41; fragmented medullae as 10.60, 8.11, 11.29; pigmented medullae as 16.27, 13.06, 16.87; and non-medullated as 29.99, 30.57, 29.51, respectively, for empty, pregnant, and lactating alpacas. It is noteworthy that reproductive status exhibited no statistically significant effect ($p>0.05$) on various forms of medullated fibers, highlighting the nuanced interplay between environmental factors and fiber medullation in Huacaya alpacas. Age significantly influenced medullation, except for fragmented fibers. Continuous medulla rose by 2% yearly, while non-medullated fibers dropped by 3.69%. Interrupted medullation peaked at 38.5% around 5.9 years. The study provides insights into the nuanced relationship between reproductive status and medullation in alpaca fibers.

KEYWORDS: medullary index; fiber quality; southeastern camelids; hardy microtome.

RESUMO: Este estudo investigou o impacto de fatores ambientais na medulação das fibras (contínua (C), interrompida (I), fragmentada (F) e não medulada (NM)) em alpacas Huacaya fêmeas de cor branca. Utilizando registros e amostras de fibra de 185 alpacas do Centro de Pesquisa e Desenvolvimento de Camelídeos Sul-Americanos Lachocc, da Universidade Nacional de Huancavelica (Peru), foram realizadas análises estatísticas pelo método de quadrados mínimos para números desiguais em subclasses. A idade das alpacas mostrou influência estatisticamente significativa no tipo de medulação das fibras, com exceção das fibras meduladas fragmentadas. As equações de regressão geradas permitiram a modelagem preditiva para medulações contínuas, interrompidas e não meduladas. Os valores médios (%) observados para medulação contínua foram de 27,45, 27,98 e 28,03; para medulação interrompida foram 33,15, 34,13 e 35,41; para medulação fragmentada, 10,60, 8,11 e 11,29; para medulação pigmentada, 16,27, 13,06 e 16,87; e para fibras não meduladas, 29,99, 30,57 e 29,51, respectivamente, para alpacas vazias, prenhes e lactantes. É relevante notar que o estado reprodutivo não apresentou efeito estatisticamente significativo ($p>0,05$) sobre as diferentes formas de medulação das fibras, destacando a interação sutil entre fatores ambientais e a medulação de fibras em alpacas Huacaya. A idade influenciou significativamente a medulação, exceto nas fibras fragmentadas. A medulação contínua aumentou 2% ao ano, enquanto as fibras não meduladas diminuíram 3,69%. A medulação interrompida atingiu o pico de 38,5% em torno de 5,9 anos. O estudo fornece insights sobre a relação sutil entre o estado reprodutivo e a medulação nas fibras de alpacas.

PALAVRAS-CHAVE: índice medular; qualidade da fibra; camelídeos sul-americanos; micrótomo de precisão.

[1]Universidad Nacional de Huancavelica, Huancavelica, Perú
[2]Universidad Nacional del Centro del Perú, Huancayo/Junín, Perú
*Corresponding author: (jninahuanca@uncp.edu.pe)
Received: 05/28/2024
Accepted: 09/17/2024

INTRODUCTION

The husbandry practices of the alpaca (*Vicugna pacos*), an indigenous Andean species, primarily center around fiber and meat production (Vila; Arzamendia, 2022; Carhuas *et al.*, 2024), due to the availability of natural pastures, which allows the producers to generate income (Ninahuanca Carhuas *et al.*, 2025). Critical to the productivity of this species is the impact of age, among various other factors (Montes *et al.*, 2008; Pollotti *et al.*, 2020). Moreover, the dynamics of lactation and gestation significantly influence fiber growth, accounting for 17% and 3%, respectively (Cruz *et al.*, 2017; Pallotti *et al.*, 2020). The alpaca fleece is intricately composed of a stratum of extended, coarser guard hairs and a stratum of fine, abbreviated, and curled fibers (Ghildival *et al.*, 2023). In this fleece configuration, the coarse hair functions as a deterrent to rainwater penetration, while the fine wool serves as an effective thermal insulator (Azam; Ahmad, 2020).

From a histological perspective, alpaca fibers exhibit a cuticular and cortical layer, occasionally featuring a medulla (Nofal, 2022). The cells within the medulla may fracture during keratinization, resulting in a hollow channel within the fiber, thereby rendering the medulla either continuous or fragmented (Gómez-Quispe *et al.*, 2022). The presence of medullated fibers is considered undesirable in production due to their adverse effects on both dyeing uniformity and garment comfort. However, medullation is not invariably a defect; its existence facilitates the thermoregulation of alpacas in challenging climates, imparting high-quality insulation and thermal properties to garments (Wang *et al.*, 2005; Moore *et al.*, 2011). Furthermore, it contributes to the lightweight nature of garments compared to those made from wool (Bonilla *et al.*, 2022).

In light of these considerations, the primary objective of this study was to ascertain the influence of age and reproductive status on alpaca fiber medullation and to delineate functional relationships among various forms of medullation. This research contributes substantively to the understanding of factors impacting alpaca fiber characteristics, thereby informing breeding practices and enhancing the quality of alpaca-derived products.

MATERIAL AND METHODS

The study was conducted at the Center for Research and Development of South American Camelids in Lachocc (CIDCSL), affiliated with the National University of Huancavelica. Situated in Huancavelica, Peru, at an elevation of 4600 meters above sea level, the CIDCSL served as the research site, this location was the origin of the animals. The identification and characterization of the 185 alpacas included in this study were derived from CIDCSL records. These animals were classified into seven age groups: four groups of 26 alpacas each, aged 1 to 4 years, and three groups of 27 alpacas each, aged 5 to 7 years. The study further divided the alpacas into three physiological status categories: 61 non-pregnant (empty) alpacas, 62 pregnant alpacas, and 62 lactating alpacas. All selected alpacas had a consistent body condition score of 3 and were maintained under exclusive grazing conditions, with their diet primarily composed of *Alchemilla pinnata, Festuca dolichophylla, Calamagrostis curvula, Poa aequigluma, Stipa obtusa, and Plantago rigida.* whose values of chemical composition per (g/kg MO) are 432.97±3.52, 327.67±3.73, 149.41±2.48, and 145.97±0.54 for Neutral Detergent Fiber, Acid Detergent Fiber, Acid Detergent Lignin and Crude Protein, respectively, according to results obtained by Waghorn and Barry (1987); and Chino Velasquez (2022).

During the shearing process, 30 grams of fiber were extracted from the left rib area of each alpaca. These samples were meticulously identified, placed, and securely sealed in polyethylene bags for subsequent analysis at the Laboratory of the Research and Social Outreach Program in Sheep and American Camelids (POCA) at the National Agrarian University La Molina in Lima. These samples underwent a washing process and were conditioned for 8 hours at a temperature of 20 ± 2°C and a relative humidity of 65 ± 5% (Radzik-Rant; Wiercińska, 2021) Subsequently, the samples were washed in a solution of 7 parts of 96% ethyl alcohol and 3 parts of benzene. Then, they were meticulously prepared into snippets measuring 1.8 to 2 mm using the Hardy microtome (5752-100-125-E-H). For each sample, the medulla type was identified using a projection microscope IWTO-8, 2011 (Bonilla *et al.*, 2022). The classification of medullated fibers into continuous, interrupted, fragmented, and non-medullated types was based on the presence and continuity of the medulla within the fiber shaft. Continuous medullas were characterized by an uninterrupted column of cells along the entire length of the fiber snippet. Interrupted medullas showed periodic gaps, while fragmented medullas exhibited smaller, isolated medullary structures (Pinares *et al.*, 2019). Non-medullated fibers, on the other hand, lacked any visible medullary cells. The classification was performed by established morphological criteria, ensuring consistent and precise differentiation of each fiber type.

The statistical model employed was: $Y_{ijk} = \mu + E_i + C_j + \varepsilon_{ijk}$, where Y_{ijk} represents the dependent variable (continuous, interrupted, fragmented, pigmented, or non-medullated), μ is a constant associated with all observations, E_i is the fixed effect of age (ranging from 1 to 7), C_j is the fixed effect of reproductive status (ranging from 1 to 3), and εijk is the random error. The data expressed as percentages of the variables under study were transformed to the square root of the arcsine percentage. The PROC GLM (General Linear Models) in with the free software

R studio (Medeiros *et al*., 2023) was employed for statistical model analysis. Variables with statistical significance had their degrees of freedom decomposed using the regression method of orthogonal polynomials. The means of the reproductive status variable were contrasted using the Tukey test (5%), previously adjusted by the least squares means (LSMEANS) method. Phenotypic correlations were determined, taking into account all levels of age and reproductive status effects.

RESULTS

Age exhibited a positive effect on continuous medulla, increasing proportionally by 2% per year of the alpaca's age, while non-medullated fibers decreased by 3.69% per year of age (Table 1). On the other hand, interrupted medullated fibers showed both linear and quadratic trends, reaching a maximum value of 38.5% interrupted medulla at 5.9 years of age. In contrast, the response of pigmented medulla was inverse to the former, with pigmented fibers decreasing to a minimum value of 12% at 4.4 years of age. Age significantly influenced ($p<0.01$) the presence of continuous, interrupted, pigmented, and non-medullated medulla, attributing 27.18%, 32.81%, 10.58%, and 30.68% of the total variation in the characteristic, respectively.

The association between fiber types is presented in Table 2. A high negative correlation was found between continuous medullated fibers and non-medullated fibers ($p<0.001$), indicating a high degree of precision in the estimation. The correlation between interrupted medullated fibers and non-medullated fibers is moderately low and negative (-0.48). Additionally, negative and statistically significant correlations of moderate and low magnitude were observed, respectively, between fragmented and pigmented medullated fibers and non-medullated fibers.

In table 3, the results indicate that the proportion of continuous medullation was consistent across all reproductive statuses, with no significant differences observed among empty (27.45 ± 0.12%), pregnant

Table 3. Estimates of the means (%) and standard error of the characteristics according to the reproductive status of the alpacas.

Type of medulation	Reproductive status		
	Empty (n=61)	Pregnant (n=62)	Lactant (n=63)
Continuous	27.45 ± 0.12[a]	27.98 ± 0.20[a]	28.03 ± 0.44[a]
Interrupted	33.15 ± 0.10[a]	34.13 ± 0.17[a]	35.41 ± 0.37[a]
Fragmented	10.60 ± 0.11[a]	8.11 ± 0.19[a]	11.29 ± 1.05[a]
Pigmented	16.27 ± 0.12[a]	13.06 ± 0.20[b]	16.87 ± 0.42[a]
Without pith	29.99 ± 0.20[a]	30.57 ± 0.34[a]	29.51 ± 0.71[a]

a,b equal letters imply similarity at level (p>0.05)

Table 1. Estimates of means (%) and coefficients of variation (%) of alpaca fiber medulation according to the age of the alpacas at the Centro de Investigación y Desarrollo de Camélidos Sudamericanos de Lachocc - CIDCSL (n=185).

Age (years)	Medullated fibers				
	Continuous[1]	Interrupted[2]	Fragmented	Pigmented[3]	Without pith[4]
1 (n=26)	21.27	25.06	11.48	19.72	40.75
2 (n=61)	21.60	28.68	6.86	17.02	42.81
3 (n=61)	25.99	37.17	10.01	11.79	31.80
4 (n=61)	33.43	33.23	9.52	13.60	25.36
5 (n=62)	30.42	38.06	10.66	14.62	25.28
6 (n=62)	29.32	39.27	8.09	14.08	24.77
7 (n=62)	32.70	38.13	13.37	16.98	19.38
X	27.18	32.81	10.58	16.05	30.68
CV	39.02	27.61	93.42	62.40	55.83

Regression equation: [1]. 19.5849+2.007X; [2]. 17.7520+7.0084X-0.5910X^2; [3]. 26.3131-6.5262X+0.7439X^2; [4]. 44.6701-3.6911X

Table 2. Phenotypic correlations ± standard error between alpaca medulation types at the Centro de Investigación y Desarrollo de Camélidos Sudamericanos de Lachocc - CIDCSL (n=185).

	Continuous	Interrupted	Fragmented	Pigmented
Interrupted	0.23** ± 0.07			
Fragmented	0.13[ns] ± 0.07	-0.004[ns] ± 0.07		
Pigmented	0.03[ns] ± 0.07	-0.27** ± 0.07	-0.03[ns] ± 0.07	
Without pith	-0.72*** ± 0.04	-0.48*** ± 0.07	-0.47*** ± 0.05	-0.23** ± 0.07

ns:(not significant: p>0.05); *** (p<0.001): ** (p<0.01)

(27.98 ± 0.20%), and lactating alpacas (28.03 ± 0.44%) (p>0.05). Similarly, interrupted medullation percentages were comparable among the groups, ranging from 33.15 ± 0.10% in empty, 34.13 ± 0.17% in pregnant, to 35.41 ± 0.37% in lactating alpacas, without significant differences (p>0.05). Although fragmented medullation tended to decrease in pregnant alpacas (8.11 ± 0.19%) compared to empty (10.60 ± 0.11%) and lactating alpacas (11.29 ± 1.05%), these differences were not statistically significant (p>0.05). Pigmented fibers exhibited a significant reduction in pregnant alpacas (13.06 ± 0.20%) compared to empty ones (16.27 ± 0.12%), while lactating alpacas (16.87 ± 0.42%) did not significantly differ from the empty group (p>0.05). Finally, non-medullated fibers showed no significant differences across the reproductive statuses, with percentages of 29.99 ± 0.20% in empty, 30.57 ± 0.34% in pregnant, and 29.51 ± 0.71% in lactating alpacas (p>0.05).

Observed values for fragmented medullated fibers did not differ significantly among the three reproductive conditions of alpacas, with an average value of 10%, much lower than the 22.8% figure found in llamas by the aforementioned authors.

DISCUSSION

The values reported in this study show slight deviations from the averages of 28.04%, 24.04%, 21.49%, and 17.58%, as documented by Pinares *et al*. (2019). These variations, when compared to the mean diameters of 7.85%, 4.86%, 9.17%, 0.72%, and 77.39% for continuous, interrupted, fragmented, pigmented, and non-medullated fibers respectively, observed by Berolatti *et al*. (2021), can be primarily attributed to a range of environmental factors, including gender, management practices, and locality. A notable factor in the present study is the exclusive assessment of females under an extensive breeding system, which could explain some of the observed differences in fiber characteristics. The trend of increasing average diameter of continuous medullated fibers with the age of the animal is consistent with findings by Martínez *et al*. (1997) in llamas and Pinares *et al*. (2019), who reported total medullation percentages increasing from 84.83% at 0.4 years to 91.67% at 10.4 years. Although limited research exists on the specific impact of age on fiber medullation in alpacas, studies by Quispe *et al*. (2021) and Olarte *et al*. (2023) and Ghildiyal *et al*. (2023) suggest that age does influence medullation types. Gelaye (2021) further supports this by observing significant differences in medullation rates across different age groups, reinforcing the idea that age is a crucial factor in determining fiber characteristics. The alignment of these findings with existing literature underscores the complexity of factors influencing medullation and highlights the need for more targeted research on the age-related changes in alpaca fiber.

The analysis of medullated fiber percentages in relation to the reproductive status of alpacas did not reveal any significant differences (p>0.05) among the groups concerning continuous medullated fibers, with an overall average of 27.82%. This figure is notably higher than the 15.3% reported by Quispe *et al*. (2009) and the 15.8% found by Frank *et al*. (2006) in llama fleeces, suggesting that alpaca fibers may inherently exhibit a greater tendency for continuous medullation compared to llamas. Nonetheless, this average is still below the 39.4% observed by Martínez *et al*. (1997) in llamas, indicating possible species-specific variations or differences in environmental and management conditions influencing fiber characteristics. The reproductive condition of the alpaca also did not significantly affect (p>0.05) the proportion of interrupted medullated fibers, which averaged 34.23%. This value is substantially higher than the 11% reported by Frank *et al*. (2006) in llamas, suggesting that interrupted medullation is more prevalent in alpacas. The consistency of these results across reproductive statuses indicates that the physiological changes associated with pregnancy and lactation may have limited impact on the structural characteristics of the fibers, particularly in terms of medullation. This could reflect a species-specific stability in fiber development during different reproductive phases, which may be a crucial factor in maintaining fiber quality across different physiological states.

CONCLUSIONS

The study demonstrates that the average diameter of continuously medullated fibers in alpacas tends to increase with the age of the animal, consistent with previous findings in South American camelids. This increase in medullation over time suggests that age is a crucial factor in the structural modification of fibers, likely due to physiological and metabolic changes associated with aging. These results underscore the importance of considering age when evaluating fiber quality in alpacas, particularly in breeding systems aimed at producing fine and high-quality fibers.

The research reveals that the reproductive status of alpacas does not significantly affect the proportions of continuously and interrupted medullated fibers. This stability in fiber structure across different reproductive phases suggests that the hormonal and physiological variations associated with pregnancy and lactation do not significantly impact fiber quality in terms of medullation. These findings are valuable for alpaca production systems, as they indicate that fiber maintains its structural integrity regardless of reproductive status, allowing for efficient herd management without compromising the quality of the produced fiber.

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