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Performance of Angora goats, mohair production, and farmer income in extensive livestock systems of north Patagonia, Argentina

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Introduction: In Argentina, mohair production is limited exclusively to the Patagonia region. This activity takes place under different biophysical conditions and with marked seasonality in the climatic conditions and productivity of natural grasslands. The present study aimed to analyze Angora goat performance, mohair production, and income in two contrasting environments of northern Patagonia.

Methods: Body weight (BW), body condition score (BCS), fleece weight (FW) and mohair samples were collected between the spring of 2019 and the autumn of 2022 on farms from the East and West regions. Fiber quality analyses included mean fiber diameter (MFD), percentage of medullated fibers (MED), and kemp fibers (KMP). Analysis of variance (ANOVA) was performed and the effects considered were region, shearing season (autumn and spring) and age. The income per shearing (IPS) was estimated based on the individual data and tender prices.

Results: In general, the BW of goats in the East was between 15% and 25% higher than that of the goats in the West ($p < 0.01$), whereas the FW difference between regions reached 25% to 32% in mature adult goats ($p < 0.01$). The autumn MFD was similar between regions ($p > 0.05$) and higher than the spring MFD ($p < 0.05$). The KMP content in the West was two-fold higher ($p < 0.01$) than that in the East (1.21%). Regarding the effect of the season, KMP and MED contents were higher in autumn than in spring ($p < 0.01$). The IPS values were lower in spring. The highest IPS value was obtained at the age of two permanent incisors. Results showed that 70 of the 100 best-ranked goats by IPS were from the East.

Discussion and conclusion: This work offers new insights for understanding characteristics of mohair production in Argentine The results suggest that winter conditions in the West negatively impact the growth and mohair production during the spring shearing. In turn, a marked seasonality in climatic conditions and in the productivity of grasslands could explain the variability of the productive performance of goats between seasons. Efforts to improve mohair incomes should focus on producing heavier, less medullated fleeces rather than finer mohair.

KEYWORDS

arid environment, body weight, fleece weight, fiber diameter, medullation, shearing income

1 Introduction

Mohair, produced by Angora goats, is one of the main textile fibers of animal origin. Its distinctive properties of smoothness and natural luster make it one of the most exclusive fibers for the design of clothing of high economic value (Pienaar et al., 2018). The world's leading mohair-producing countries are South Africa and Lesotho, with Argentina being the third largest producer, producing 11% of the world's total and 470 tons per year (Sacchero, 2019).

In Argentine Patagonia, production is limited to the provinces of Neuquén, Río Negro, and Chubut, and is established in extensive mixed livestock systems of sheep and goats by small producers of family, peasant, and indigenous agriculture (Villagra et al., 2015). This production is one of the strategies for the economically productive diversification of regional livestock, where fiber provides a source of farmer income that is complemented by the income from meat. In addition to its productive function, the extensive livestock production of Patagonia allows for the rooting of the population and supports the economic structure, contributing to sustainable rural development and to the maintenance of agroecosystems of high natural and cultural value.

In Argentina, limited studies have been performed on Angora goat systems, but it is known that both the production and the quality of mohair are highly variable between and within herds and are largely influenced by the environment, genetics, and age, among other factors. These systems are characterized by a strong dependence on natural resources and low capital and technology input (Easdale et al., 2009; Villagra and Giraudo, 2010; Villagra et al., 2015). This activity takes place under different biophysical conditions (Bran et al., 2000; Jobbágy et al., 2002) and with a marked seasonality in the climatic conditions and productivity of natural grasslands (Paruelo et al., 1998; Jobbágy et al., 2002; Fabricante et al., 2009). These conditions usually cause nutritional deficiencies in younger animals, manifested from their birth in spring (October–November) (Taddeo et al., 1998; Mueller et al., 2018). These nutritional deficiencies are associated with low percentages of kidding and weaning, and high mortality during the first winter due to the low-quantity and low-quality grazing and low temperatures (Taddeo et al., 1998; Mueller et al., 2018). In turn, during the first 2 years of life, these deficiencies affect mohair production and quality (McGregor et al., 2010). In different Angora goat herds in Patagonia, fleece weight (FW) can vary from 1.2 to 3.0 kg (Taddeo et al., 1998; Abad et al., 2002). Important variations have also been verified in mohair quality features such as mean fiber diameter (MFD), medullation content (MED), and kemp-type fibers (KMPs) (Sacchero et al., 2021). The introduction of Australian and New Zealand germplasm during 2002–2005 had a positive impact on quality indicators such as a MFD of less than 29 μm until the third shearing and KMP percentages lower than 1% in the first shearing. However, problems of body size failure, rusticity, and environmental adaptation have also been repeatedly reported (Mueller et al., 2018).

In the Argentine commercial system, the price of mohair depends on the MFD. However, in recent years, with the incorporation of international traders, the MED and KMP content have also begun to be considered in the price, as rewards or punishments, a fact that impacts the fiber quality and the economic farmer income achieved (*Programa Mohair*[1], personal communication). In response to industry demands, such as requirements for fiber lengths up to 150 mm and lower levels of felting, the mohair harvest has gradually incorporated a double annual shearing scheme, in autumn and spring, replacing the traditional shearing in spring only.

Despite the importance of mohair in livestock systems in Argentine Patagonia, the influence of environmental conditions and the seasonal fluctuations on the variability of its production and quality is unknown. Thus, the study aimed to evaluate individual Angora goat production traits, the quality of mohair, and farmer income from fiber in livestock commercial farms located in contrasting environments in the province of Río Negro.

2 Materials and methods

2.1 Study area

The work was carried out in the province of Río Negro, located in the north of Argentine Patagonia (Figure 1), in six commercial

1 About 10% of Argentina's mohair production is within the *Programa Mohair*. This program, initiated in 1998, is a sectoral public policy focused on addressing productive (genetic improvement), commercial (fiber conditioning and classification) and socio-organizational issues for Angora goat breeders.

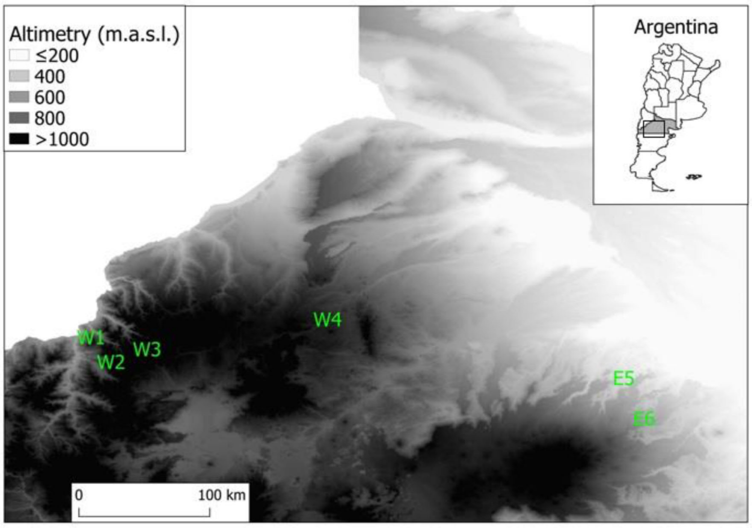

FIGURE 1
Study area in the province of Río Negro, Argentina. The farms used in the study are identified by letters and numbers ("W" for the West and "E" for the East). The grayscale shows the altitude (masl) of the farms.

farms longitudinally dispersed over 436 km and located between approximately 1,200 and 300 meters above sea level (masl). The longitudinal gradient contains important environmental contrasts in terms of altitude, rainfall, mean annual temperature (Table 1), pasture productivity, and livestock receptivity between the farms located in the East (n = 4) and those located in the West (n = 2).

2.2 Mohair growth period, animal production records, and fiber sampling

From the spring shearing of 2019 until the autumn shearing of 2022, at least 25 female goats were sampled from each farm (Picture 1). Samplings were conducted on five females taken at

TABLE 1 Main biophysical characteristics of the livestock farms studied.

Region	Flock size	Relief	Altitude (masl)	Precipitation and regime	Temperature (°C)	Vegetation
West 1 (W1)	100	Hills and basaltic plateaus	1,008	190 mm Mediterranean, concentrated in autumn and winter	Annual average: 8–10; Max: 17; Min: 2	Shrub-grass steppe (*Mulinum spinosum*, *Senecio* spp., *Poa speciosa* var. major, *Festuca pallescens*)
West 2 (W2)	170	Hills and basaltic plateaus	1,151	190 mm Mediterranean, concentrated in autumn and winter	Annual average: 8–10; Max: 17; Min: 2	Shrub-grass steppe (*Mulinum spinosum*, *Senecio* spp., *Poa speciosa* var. major, F. *pallescens*)
West 3 (W3)	200	Hills and basaltic plateaus	1,263	190 mm Mediterranean, concentrated in autumn and winter	Annual average: 8–10; Max: 17; Min: 2	Shrub-grass steppe (*Mulinum spinosum*, *Senecio* spp., *Poa speciosa* var. major, *Festuca pallescens*)
West 4 (W4)	180	Hills and basaltic plateaus	1,140	160 mm Mediterranean, concentrated in autumn and winter	Annual average: 8–12; Max: 19; Min: 3	Shrub steppe (*Nassauvia glomerulosa*, *Nassauvia axillaris*, *Chuquiraga avellanedae*, *Prosopis denudans*, *Jarava humilis*)
East 1 (E1)	230	Peniplains and sedimentary plateaus	301	180 mm Isohygric, autumn and spring	Annual average: 13–14; Max: 22; Min: 6	Shrub steppe (*Larrea nitida*, *Larrea divaricata*, *Larrea cuneifolia*, *Atriplex* spp., *Stipa tenuis*)
East 2 (E2)	160	Peniplains and sedimentary plateaus	508	180 mm Isohygric, autumn and spring	Annual average: 13–14; Max: 22; Min: 6	Shrub steppe (*Larrea nitida*, *Larrea divaricata*, *Larrea cuneifolia*, *Atriplex* spp., *Stipa tenuis*)

Source: Bran et al., 2005; AIC, 2023. Reference: Max, mean maximum temperature of January; Min, mean minimum temperature of July.

random from each of the age categories found in the herd: milk tooth (MT), two permanent incisors (2T), four permanent incisors (4T), six permanent incisors (6T), full mouth (FM), and permanent teeth worn down to half their original height (HT). At some shearings (farms or seasons) the HT category was not found and only five age categories were sampled. For the MT category, the first shearing is carried out in spring.

Individual production was recorded through greasy fleece weight (FW, measured to the nearest 5 g), including records of fleece-free body weight (BW, measured to the nearest 0.1 kg), and body condition score (BCS) by palpating the spinous processes of the lumbar vertebrae (McGregor, 1992). Finally, individual mid-side fleece samples were taken at shearing and stored in labeled plastic bags for fiber quality analysis.

2.3 Analysis of samples in the laboratory

Each of the mohair samples was washed according to the procedures of the method for determination of washing yield and clean fleece weight (AS/NZS, 2000). Once washed, the MFD (μm) was determined by means of an OFDA2000® fiber diameter analyzer (IWTO 47, 2013) and the medullation content was analyzed by microprojection (IWTO 8, 1998). Continuous and discontinuous medullated fiber (MED, %) as a whole and kemp-type fiber (KMP, %) content were determined.

2.4 Estimates of farmer income per shearing

The farmer income per shearing (IPS, US$) for each goat was estimated based on their FW and MFD, and on the price per kilogram of fiber. The price per kilogram of fiber used was obtained from the public auctions carried out by the *Programa Mohair* in each season and based on the MFD of each goat according to the following categories: Kid (MFD < 27 μm), Young (MFD between 27 and 30 μm), and Adult (MFD > 30 μm).

2.5 Statistical analysis

Descriptive analyses were performed to obtain summary statistics for each variable. Analysis of variance (ANOVA) was performed using the general linear model procedures (PROC GLM) of the SAS statistical package (SAS, 2010). Hypothesis testing was performed with a significance level of 5%. The fixed effects considered were year, region, shearing season, age of the goats, and the interactions of these effects. Non-significant interactions were removed from the model. The model is expressed according to

$$y_{ijkl} = \mu + \alpha_i + \beta_j + \delta_k + \tau_l + (\beta\delta)_{jk} + (\beta\tau)_{jl} + (\delta\tau)_{kl} + e_{ijkl}$$

Where y_{ijkl} represents the response variable to study (e.g., MFD, FW), μ represents the mean value of the response variable ,α_i is the effect of year, β_j is the effect of region (j = East and West), δ_k is the effect of shearing season (k = autumn and spring), τ_l is the effect of age (l = MT, 2T, 4T, 6T, FM and HT), $(\beta\delta)_{jk}$ is the region and shearing season interaction, $(\beta\tau)_{jl}$ is the region and age interaction, and $(\delta\tau)_{kl}$ is the shearing season and age interaction. The year effect was included in the model but was not of interest and therefore was not analyzed.

For the IPS variable, the median, minimum, and maximum were estimated.

3 Results

Table 2 summarizes the significance of the effects of the region, season, and age on mohair production and the quality variables studied.

3.1 Production variables

3.1.1 Body weight

BW was significantly affected by the region × season and region × age interactions. The region × season interaction results showed that, in the East, BW values were similar between seasons, whereas, in the West, the BW values in spring were 22% lower than those in autumn (difference of 6.0 kg; p<0.001) (Table 3).

Regarding the region × age interaction, results showed that the BWs of the goats of the East and West were similar only at the

TABLE 2 Significance of the effects of region, season, age, and their interactions on production variables and mohair quality of Angora goats from Argentine Patagonia.

Variable	n	Region	Season	Age	Region × season	Region × age
Body weight	363	*	*	*	*	*
Condition score	448	*	*	*	*	–
Fleece weight	529	*	*	*	*	*
Mean fiber diameter	568	*	*	*	*	*
Medullation percentage	568	*	*	ns	–	*
Kemp percentage	568	*	*	ns	–	–

*differences lower than 0.05; ns, non-significant differences; -interactions removed from the model.

TABLE 3 Least squares means (± SE) values for body weight, body condition score, fleece weight, and mean fiber diameter for Angora goats from Argentine Patagonia by region and shearing season.

Region	Shearing season	Body weight (kg)	Body condition score	Fleece weight (g)	Mean fiber diameter (μm)
East	Autumn	29.4 ± 0.77 a	2.33 ± 0.04 ab	1221 ± 41.0 a	32.4 ± 0.48 a
	Spring	30.0 ± 0.61 a	2.31 ± 0.03 b	1150 ± 22.0 a	30.0 ± 0.20 b
West	Autumn	27.3 ± 1.15 a	2.45 ± 0.07 a	1117 ± 43.0 a	31.3 ± 0.36 a
	Spring	21.3 ± 0.43 b	1.91 ± 0.02 c	740 ± 39.0 b	28.2 ± 0.25 c

East and West, regions involving contrasting environments of Patagonia. Different letters within same column correspond to significant differences ($p < 0.05$).

beginning of their life. The MT and 2T goats showed differences of 4.5 and 3.5 kg, respectively, whereas, from the 4T to the HT goats, the differences in BW became significant and increased progressively from 6.5 to 9.3 kg (Figure 2). In general, the BW of goats in the East was between 15% and 25% higher than that of the goats in the West.

3.1.2 Body condition score

BCS values were affected by the region × season interaction and age. The region × season interaction showed that, in the East, the BCS at shearing was similar in autumn and spring, whereas, in the West, the BCS values in spring were significantly lower than those in autumn (Table 3). Regarding the effect of age, marginally significant differences (p=0.035) of 0.13 were observed between the age classes with the highest and lowest BCS values (2.31 for 4T and 2.18 for 2T goats). This difference, however, is of no practical importance and not discriminable by the method.

3.1.3 Fleece weight

FW was significantly affected by the region × season and region × age interactions. The region × season interaction showed that, in the East, fiber production was similar between seasons. On the other hand, in the West, lower values occurred in spring than in the autumn, representing a decrease of 17.8% (Table 3).

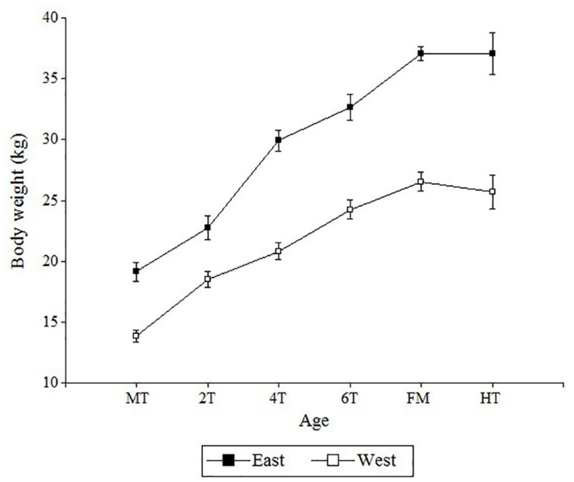

FIGURE 2
Body weight of Angora goats according to their ages and regions. MT, milk tooth; 2T, two teeth; 4T, four teeth; 6T, six teeth; FM, full mouth; and HT, half a tooth. East and West: regions involving contrasting environments.

The region × age interaction showed FW differences between regions for FM and HT goats, which were heavier (by 25% and 32%, respectively) in the East than in the West. In the East, the values for FM and HT goats were 1,299 ± 32 g and 1,325 ± 53 g, while in the West they were 976 ± 38 g and 894 ± 76 g, respectively. Also, in the East, goats increased their FW with age, but in the West they seemed to reach maximum FW values earlier in their life, at the age of 6D (Figure 3).

3.2 Fiber quality variables

3.2.1 Mean fiber diameter

MFD was significantly affected by the region × season and region × age interactions. The region × season interaction showed that, in both regions, the autumn MFD was higher than the spring MFD and similar between regions (Table 3). On the other hand, the spring values in the West were lower than those in the East (Table 3). Regarding the region × age interaction, differences in MFD were observed for 6T and FM goats, with coarser fibers in the East (32.3 ± 0.49 μm and 33.4 ± 0.29 μm, respectively) than in the West (29.9 ± 0.43 μm and 30.5 ± 0.30 μm, respectively).

3.2.2 Medullation content

The MED content was significantly affected by the shearing season and by the region × age interaction. Regarding the effect of the season, the MED content was higher in autumn than in spring (3.17% ± 0.19% *vs.* 2.33% ± 0.10%). The interaction showed differences for only MT goats between regions (1.22% ± 0.33% in the East *vs.* 2.95% ± 0.39% in the West).

3.2.3 Kemp content

The KMP content was significantly affected by the region and the shearing season. The KMP content in the West (2.44% ± 0.11%) was two-fold higher than that in the East (1.21% ± 0.11%) ($p<0.01$), and the KMP content in autumn (2.25% ± 0.16%) was higher than that in spring (1.39% ± 0.09%).

3.3 Estimates of farmer income per shearing

Table 4 presents summary measures (median, minimum, and maximum) of the IPS for the combination of season and region and for the different age groups. The results shown in this table reflect that the IPS values were lower in spring.

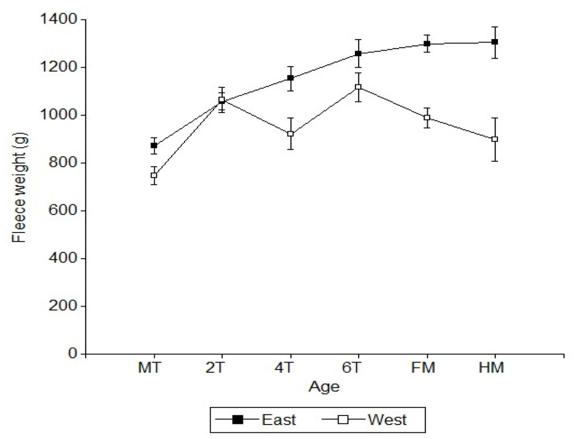

FIGURE 3
Fleece weight of Angora goats according to their ages and region. MT, milk tooth; 2T, two teeth; 4T, four teeth; 6T, six teeth; FM, full mouth; and HT, half a tooth; East and West, regions involving contrasting environments of Patagonia.

In the East, the spring IPS was 12% lower than the autumn IPS, whereas in the West the difference was more marked, with the spring approximately 33% lower than the autumn IPS. On the other hand, the spring IPS was 33% lower in the West than in the East. For age groups, the highest IPS was observed in 2T goats.

Finally, a ranking based on IPS values (n=504) showed that 70% of the 100 best-ranked goats were from the East and that 72% of the 100 worst-ranked goats were from the West.

4 Discussion

The objective of this work was to analyze the productive performance of Angora goats, their mohair production, and farmer income from fiber in the extensive systems of Argentine Patagonia. The results suggest that, in the regions studied, the environmental conditions affect goat growth and mohair production. For example, the lower annual temperatures and higher altitudes of the farms in the West limit, to a greater extent, the productive performance of goats in that region (Table 3, Figures 1, 2). In South African production systems, the susceptibility of Angora goats to cold weather generates high mortality rates in adults in addition to high mortality rates in kids and low reproductive rates in females (Snyman, 2010; Snyman and Van Heerden, 2021). In turn, a marked seasonality in climatic conditions and in the productivity of natural grasslands (Paruelo et al., 1998; Jobbágy et al., 2002; Fabricante et al., 2009) could explain the variability of the productive performance of goats between seasons. The physiological condition of goats could have also affected the growth of mohair, as spring coincides with the end of gestation.

4.1 Productive variables

The results for the variables of growth and mohair production showed the same behavior, characterized by a worse performance (lower values of BW, BCS, and FW) during spring in the farms in the West (Table 3). This region is characterized by a higher altitude (between 1,008 and 1,263 masl) and winters with low average temperatures, snowfall, and scarcity of forage during the winter season (Bran et al., 2000; Bran et al., 2005). In Patagonian environments, previous studies have shown that the low availability and quality of pasture may lead to nutritional deficiencies during the winter months—i.e., prior to the spring shearing—and have been associated with low percentages of kidding and weaning and high mortality during the first winter (Taddeo et al., 1998). These problems have been repeatedly

TABLE 4 Median, minimum, and maximum values of farmer income per shearing (IPS) in US dollars for the combination of season and region and for the different age classes of Angora goats of Argentina.

Factors		Classes	n	Median	Minimum	Maximum
East	Autumn		24	14.5	8.8	20.8
	Spring		255	12.7	3.5	35.9
West	Autumn		88	12.7	4.7	24.6
	Spring		137	8.5	2.5	32.5
Age		MT	58	9.0	3.5	25.3
		2T	71	15.1	5.3	35.9
		4T	56	10.3	4.4	28.7
		6T	82	11.8	2.9	23.7
		FM	172	11.7	2.5	33.8
		HT	53	13.2	4.3	30.5

IPS, estimation based on individual's fleece weight and mean fiber diameter and on the price per kilogram of fiber obtained at regional public auctions. Age: MT, milk tooth; 2T, two teeth; 4T, four teeth; 6T, six teeth; FM, full mouth; and HT, half a tooth. East and West: regions involving contrasting environments.

associate to a lack of rusticity and environmental adaptation of the Angora breed (Mueller et al., 2018) or as susceptibility to cold stress (McGregor and Butler, 2008; Snyman, 2010).

The growth difficulties of goats in the West were also evidenced in low BCS values in the spring shearing, a consequence of the previous winter conditions. The results of McGregor and Butler (2008) indicated that a low BCS of goats at the time of shearing is heavily associated with the prediction of susceptibility to cold stress and hypothermia.

When comparing the BW values in spring for adult goats from the East (32.7 kg ± 0.35 kg; average for ages 6T, FM, and HT) with those of goats from other parts of the world, we found that the BW values found in the present study are similar to those reported in South Africa (35.2 kg) by Snyman (2019) and in Australia (34.5 kg) by McGregor (2016). However, the values found in adult goats from the West in that season were lower (29.3 kg ± 0.46 kg). To improve this feature, germplasm of South African origin have recently been introduced under the *Programa Mohair*.

Regarding the FW, the results obtained in the West show that this variable was also significantly affected by the season because the lowest values of hair production were obtained in spring. In South Africa, for shearing adjusted to 180 days of growth, Snyman (2019) reported FW values of 1,360 g and 1,270 g for the second and third shearing, respectively, and values of 1,460 g for adult females, whereas in Australia McGregor (2020) reported FW values of 1,170 g and 1,340 g for the second and third shearing, respectively. In the present study, the mean FW values for the second and third shearing of adult goats were 1,060 g and 1,047 g, respectively. In Australia, for the first shearing of kids, McGregor (2020) reported a value of 730 g, whereas, in this work, the FW value was 823 g (n = 58). These results would indicate that Argentine mohair production may be increased through technological innovation, genetic selection, or a combination of both.

In the East, the low variability observed for the variables BW, BCS, and FW between seasons could be related to the biophysical characteristics of that region defined by the isohydric rainfall regime, higher average temperatures, milder winters, and lower altitudes (Bran et al., 2000; Bran et al., 2005; Godagnone and Bran, 2009), which result in smaller fluctuations in grassland productivity (Paruelo et al., 1998; Fabricante et al., 2009).

4.2 Mohair quality

4.2.1 Mean fiber diameter

MFD values reflected the variability of environmental conditions between seasons. In spring, fiber refinement was observed in both regions, whereas the decrease in diameter was greater in the West than in the East (Table 3). This result coincides with the lower productive performance for BW, BCS, and FW described in Table 3. The environmental effect on fiber diameter in mohair has been previously observed (Huston et al., 1990 cited in Hunter and Botha, 2022).

In the changes with age observed for MFD, fiber diameters of less than 25 µm at the first shearing (MT category) stand out, with a MFD of 24.8 µm coinciding with that expected in the international classification for the “Kid” category. Then, MFD showed a significant increase (3.6 µm on average) in the next shearing, with diameters of 28.4 and 29.8 µm for 2T and 4T goats, respectively, matching that expected for the “Young” category. This agrees with that observed by Mueller et al. (2018), who found that among the main achievements of the genetic improvement carried out by the *Programa Mohair* is that the MFD remains below 30 µm until the third shearing. The rest of the age categories, e.g., the adult and old goats of categories 6T, FM, and HT, showed MFD values above 30 µm (32.1 µm), which correspond to the international “Adult” category.

The MFD values obtained in this work were lower than those reported in Turkey and Tajikistan. In Turkey, Şenyűz (2021) reported MFD values of 28.3 µm in the first year of life, 30.7 µm in the second, and between 31.9 and 35.5 µm for animals that were 3–8 years of age. In Tajikistan, for mohair of different colors sheared in spring, Kosimov et al. (2013) found values of 27.3 µm in the first year of life, 31.3 µm in the second, and 34.6 µm for animals that were 3–5 years of age.

4.2.2 Medullation and kemp

Mohair quality is downgraded by the presence of medullated fibers because this directly affects the ability to dye the fibers. In this work, some goats exceeded 2% KMP and therefore would not meet the requirements for first-class mohair (Newman and Paterson, 1999). Both MED and KMP contents were higher in autumn mohair than in spring mohair, consistent with the findings of Lupton et al. (1991) and Litherland et al. (2000). The total content of medullated fibers reached 5.46% (3.21% MED and 2.25% KMP) in autumn and 3.72% (2.33% MED and 1.39% KMP) in spring. In other words, in autumn, the KMP content also increased in value relative to the total, going from 37% to 41%, while the MED fibers reduced their relative contribution from 63% to 59%. The medullation percentages found in this study were higher than those found in South Africa (<1.5%; Hunter and Botha, 2022) and showed different contributions of continuous and discontinuous medullated fibers and kemps.

Previous work in provincial stockpiles marketed through the *Programa Mohair* found MED values of up to 3.5% and a sustained increase in KMP content since 2014, exceeding 1% in 2018 (Sacchero, 2019). The high values of MED and KMP found in both regions (2.40% and 1.21%, respectively, for the East and 2.98% and 2.44%, respectively, for the West) reflect the importance of using bucks with objective measures of MED and KMP, which could generate positive impacts on the quality of Argentine mohair.

No presence of KMP was detected in fleeces from the first shearing of kids of the MT category (1%), as it is not customary to perform the shearing of this category in autumn but in the following spring (when they are about 10 months old) and when the birth coat is fully lost (Hunter and Botha, 2022). In these kids (MT), we found differences in MED between the East and the West (see 3.2.2). Huston et al. 1990 cited in Hunter and Botha, 2022 found no effect of age on MED or KMP levels.

4.3 Estimated farmer income per shearing

The IPS obtained in spring was lower than that obtained in autumn (Table 4). This was more largely evidenced in the West (with a difference of US$4.2 between seasons) than in the East (with a difference of US$1.8 between seasons). In turn, the greatest difference between minimum and maximum prices was observed in spring. The lower FW observed in spring (Table 3) could have a greater impact on the IPS values. On the other hand, the higher values of MFD in autumn did not have a negative impact on the IPS. This would indicate that farmer incomes from fiber are more sensitive to fluctuations in mohair production (FW) than to fluctuations in mohair quality (MFD). This is partly explained by the wide ranges of fineness (3 µm), which imply price changes between the Kid, Young, and Adult categories.

The maximum IPS values (US$15.1) were obtained in the 2T category (Table 4). These goats produced fleeces of 1,060 g (Figure 3), with an MFD lower than 30 µm, producing a more profitable combination. In South Africa, for adult goats, Snyman (2019) reported farmer from the sale of hair of US$17.50–18.00. On the other hand, the profitability of the MT category, despite producing high-value mohair (i.e., finer), was the lowest (US$9.00), mainly due to low FW values. The higher number of goats from the East in the top 100 of the IPS ranking opens up a future line of research to understand the global implications in the Angora goat systems in Argentina.

The IPS plays a very important role in these production systems, since the production of fiber is less variable than that of meat and, even in the face of extreme environmental conditions, provides a more stable source of economic farmers income to the producer (Villagra et al., 2015; Easdale and Rossso, 2010). In South Africa, Snymam (2019) also found greater annual variation in farmer income from reproduction than in the farmer income from mohair. This farmer income could increase significantly by improving marketing, as the prices obtained in public auctions of the *Programa Mohair* are close to 50% of the value paid in South Africa for the same fineness (Mohair South Africa). For example, for the seasons analyzed, the values obtained were US$6.75–12.55 per kg for the Adult category, US$9.15–16.85 per kg for the Young category, and US$9.60–21.75 per kg for the Kid category.

5 Conclusions

Knowledge of the characteristics of mohair production at a farm level is essential to monitor and review the actions carried out within the framework of public policies that are focused on sustainably increasing agricultural productivity and farmer incomes, adapting and creating resilience to climate change, and reducing and/or absorbing greenhouse gasses.

The results of this work suggest that winter conditions in the West negatively impact the variables evaluated during the spring shearing, leading to a lower BW, lower body condition, and lower FW. Current indicators can be improved through appropriate technologies and genetic improvement. Efforts to improve mohair farmer incomes from mohair should focus on producing heavier, less medullated fleeces rather than finer mohair.

Data availability statement

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

Ethics statement

Normal practice of shearing and weighting animals at farm level. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

DS: conceptualization, methodology, software, validation, statistical analysis, investigation, resources, writing—original draft, writing—review and editing, supervision. EG: conceptualization, statistical analysis, graphics tools and maps, resources, writing—original draft, writing—review and editing. JM: conceptualization, statistical analysis, writing—original draft, writing—review and editing, resources, supervision. ML: on-field work and sampling, investigation, resources, supervision. MC: on-field work and sampling, investigation, resources, review. RA: on-field work and sampling, investigation, resources, supervision. FB: on-field work and sampling, investigation, resources, supervision. 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.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fanim.2023.1208778/full#supplementary-material

PICTURE 1
Angora goats from a herd in Argentine Patagonia. Photo: Diego Sacchero.

References

(AIC) (Accessed February 2023).

Abad, M., Arrigo, J., Gibbons, A., Lanari, M. R., Morris, G., and Taddeo, H. R. (2002). "Breeding scheme for angora goat production in north Patagonia," in *Proceedings 7th World Congress on Genetics Applied to Livestock Production*, Montpellier, France, August 19 – 23. 12–14.

AS/NZS (2000). Australia/New Zealand Standard, 4492.2.2000. Wool: fleece testing and measurement. Method 2: Determination of washing yield and clean fleece weight.

Bran, D., Ayesa, J., and Lopez, C. (2000). *Regiones ecológicas de Rio Negro* (INTA Bariloche: Comunicación Técnica No. 59).

Bran, D., Oliva, G., Rial, P., Escobar, J., López, C., Umaña, F., et al. (2005). *Regiones ecológicas homogéneas de la Patagonia Argentina* (INTA Bariloche: Comunicación Técnica No. 132).

Easdale, M. H., Aguiar, M. R., Román, M., and Villagra, E. S. (2009). Socio-economic comparison of two biophysical regions: livestock production systems from río Negro province, Argentina. *Cuadernos desarrollo Rural* 6 (62), 173–198.

Easdale, M. H., and Rossso, H. (2010). Dealing with drought: social implications of different smallholder survival strategies in semi-arid rangelands of northern Patagonia, Argentina. *Rangeland J.* 32, 247–255. doi: 10.1071/RJ09071

Fabricante, I., Oesterheld, M., and Paruelo, J. M. (2009). Annual and seasonal variation of NDVI explained by current and previous precipitation across northern Patagonia. *J. Arid Environments* 73 (8), 745–753. doi: 10.1016/j.jaridenv.2009.02.006

Godagnone, R. E., and Bran, D. E. (2009). *Inventario integrado de los recursos naturales de la provincia de río Negro: geología, hidrología, geomorfología, suelos, clima, vegetación y fauna*. Ediciones INTA).

Hunter, L., and Botha, A. (2022). The relationship between medullated fibres and angora goat age and fibre diameter distribution in commercial mohair sale lots. *J. Natural Fibers* 19 (16), 14131–14145. doi: 10.1080/15440478.2022.2116624

IWTO 47 (2013). *Measurement of the mean and distribution of fiber diameter of wool using an optical fiber diameter analyzer (OFDA)* (Ilkley, Yorkshire, UK: International Wool Textile Organisation).

IWTO 8 (1998). *Method of determining fibre diameter distribution parameters and percentage of medullated fibres in wool and other animal fibres by projection microscope* (Ilkley, Yorkshire, UK: International Wool Textile Organisation).

Jobbágy, E. G., Sala, O. E., and Paruelo, J. M. (2002). Patterns and controls of primary production in the Patagonian steppe: a remote sensing approach. *Ecology* 83 (2), 307–319. doi: 10.1890/0012-9658(2002)083[0307:PACOPP]2.0.CO;2

Kosimov, F. F., Kosimov, M. A., Rischkowsky, B., and Mueller, J. P. (2013). Evaluation of mohair quality in angora goats from the northern dry lands of Tajikistan. *Small Ruminant Res.* 113, 73–779. doi: 10.1016/j.smallrumres.2013.02.002

Litherland, A. J., Toerien, C., Sahlu, T., Lee, P., and Goetsch, A. L. (2000). Effects of season on fleece traits of angora does in the US. *Small Ruminant Res.* 38, 63–670. doi: 10.1016/S0921-4488(00)00135-8

Lupton, C. J., Pfeiffer, F. A., and Blakeman, N. E. (1991). Medullation in mohair. *Small Ruminant Res.* 5, 357–365. doi: 10.1016/0921-4488(91)90073-Y

McGregor, B. (1992). Body composition, body condition scores and carcass and organ components of grazing angora goats. *Proc. Aust. Soc. Anim. Production* 19, 273–276.

McGregor, B. A. (2016). Allometric relationships determined for skin area and fleece production of angora goats. *Small Ruminant Res.* 145, 28–32. doi: 10.1016/j.smallrumres.2016.10.018

McGregor, B. A. (2020). Development and growth of mohair fleeces from birth and relationships between skin follicle populations, mohair physical properties, animal size and fleece value. *Small Ruminant Res.* 189, 106–142. doi: 10.1016/j.smallrumres.2020.106142

McGregor, B. A., and Butler, K. L. (2008). Relationship of body condition score, body weight, stocking rate and grazing system to the mortality of angora goats from hypothermia and their use in the assessment of welfare risks. *Aust. Veterinary J.* 86, 12–17. doi: 10.1111/j.1751-0813.2007.00249.x

McGregor, B. A., Harris, R., and Denney, G. (2010). Influence of grain supplements during winter on liveweight, mohair growth and mohair quality of weaner angora goats. *Anim. Production Sci.* 50, 593–598. doi: 10.1071/AN09222

Mohair sudáfrica. auction reports. Available at: https://www.mohair.co.za/.

Mueller, J. P., Taddeo, H. R., Abad, M. I., and Debenedetti, S. (2018). Revisión sobre el origen y el desarrollo de la producción de caprinos de angora en Argentina. *Rev. Investigaciones Agropecuarias* 44, 286–300.

Newman, S. A., and Paterson, D. J. (1999). Variation in fibre and fleece characteristics between and within south African, new Zealand, and south African x new Zealand angora goat genotypes. *New Z. J. Agric. Res.* 42 (1), 77–82. doi: 10.1080/00288233.1999.9513355

Paruelo, J. M., Beltran, A., Jobbagy, E., Sala, O. E., and Golluscio, R. A. (1998). The climate of Patagonia: general patterns and controls on biotic processes. *Ecología Austral* 8 (2), 85–101.

Pienaar, L., Partridge, A., and Morokong, T. (2018). *The mohair industry: economic impact of possible market closure* (Elsenburg: Agricultural Economics Services Western Cape Department of Agriculture).

Şenyűz, H. H. (2021). Fertility, live weight, survival rate, greasy fleece weight, and quality traits of angora goats in Turkey. *Small Ruminant Res.* 197, 106332. doi: 10.1016/j.smallrumres.2021.106332

Sacchero, D. M. (2019). Calidad del mohair producido en la Patagonia en el último lustro. *Rev. Argent. Producción Anim.* 39 (1), 21–29.

Sacchero, D. M., López, M., Cortés, M. V., Álvarez, R., and Bidinost, F. (2021). *Producción individual de mohair en sistemas ganaderos extensivos de río Negro, Argentina* (La Rioja, Argentina: 3° Congreso Argentino de Producción Caprina).

SAS (2010). *SAS/STAT software, version 9.3 of the SAS system for windows 7* (Cary, NC, USA: Copyright© 2008 SAS Institute Inc).

Snyman, M. A. (2010). Influence of body weight, age and management system on reproduction of south African angora goats does. *South Afr. J. Anim. Sci.* 40 (1), 41–53. doi: 10.4314/sajas.v40i1.54129

Snyman, M. A. (2019). Hair production, reproduction and income of angora goat ewes that had five or six kidding opportunities in the flock. *Grootfontein Agric.* 19 (1), 1–19.

Snyman, M. A., and Van Heerden, M. (2021). Effect of protective coats on physiological parameters of angora kids exposed to cold, wet and windy conditions: an advanced study. *In: Cutting-edge Res. Agric. Sci.* 8, 1–14. doi: 10.9734/bpi/cras/v8/7947D

Taddeo, H. R., Allain, D., Mueller, J. P., and De Rochambeau, H. (1998). Factors affecting fleece traits of angora goat in Argentina. *Small Ruminant Res.* 28, 293–298. doi: 10.1016/S0921-4488(97)00091-6

Villagra, E. S., Easdale, M. H., Giraudo, C. G., and Bonvissuto, G. L. (2015). Productive and income contributions of sheep, goat and cattle, and different diversification schemes in smallholder production systems of northern Patagonia, Argentina. *Trop. Anim. Health Production* 47, 1373–1380. doi: 10.1007/s11250-015-0873-9

Villagra, E. S., and Giraudo, C. G. (2010). Aspectos sistémicos de la producción ovina en la provincia de río Negro. *Rev. Argent. Producción Anim.* 30 (2), 211–224.