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PRODUCTION AND ECONOMIC EVALUATION OF THE CORRIEDALE BREED AND CROSSES WITH DOHNE MERINO GENERATED DURING THE ESTABLISHMENT OF A ROTATIONAL CROSSBREEDING SCHEME: EWE HOGGET RESULTS

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ABSTRACT

Corriedale (C) is the predominant sheep breed in Uruguay, but prices for its medium fineness wool have been low. Dohne Merino (DM) has attracted interest because it has similar attributes to C, but finer wool. We evaluated wool and body traits of crossbred ewe hoggets generated during the establishment of a rotational crossbreeding scheme between C and DM. The program started with 400 C ewes. The first year 100 C ewes were mated to C rams, and the rest were mated to DM. Purebred C progeny were always mated to C rams. The crossbred progeny was randomly divided into two equal groups, one of which was mated to C rams and the other to DM rams. Subsequent progenies were mated to rams of the opposite breed to its sire. Performance was recorded from 2015 to 2020 in the ewe hoggets. Gross margin (GM) was calculated for each genotype. Differences among genotypes for subjectively assessed wool quality traits were non-significant. Genotypes with a greater proportion of C had higher fleece weight, whereas those with a greater proportion of DM had lower fibre diameter. Pure C had the lowest post-shearing live weight whereas ½DM_½C had the highest. Pure C had the lowest GM for the scenarios investigated (low and high wool price, adjustment for greater feed intake of heavier hoggets). Rotational crossbreeding takes advantage of the complementarity between these two breeds, allowing a rapid enhancement of the C producers' income from wool without compromising the meat-producing attributes of the breed. The advantage could be greater by implementing some simple selection strategies.

Keywords: complementary breeds, dual purpose, wool production, wool quality, gross margin.

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INTRODUCTION

The number of sheep in Uruguay has been steadily decreasing, from 25 million in 1990, to 6.34 million in 2020 (Montossi et al., 2013; MGAP, 2021). Factors such as the increment of areas occupied by agriculture, forestry, and dairy and beef cattle production, have contributed to the decline.

The Corriedale (C) breed was introduced in 1912. It has historically been the numerically most important breed in Uruguay (42% of the national flock, MGAP, 2018). In a breeding flock, its wool typically varies between 25 and 31 microns in fibre diameter. The relatively low price for wool of this fineness (Bottaro, 2013; Cardellino et al., 2018) has led producers to consider breeds with attributes similar to those of C, but that produce wool of greater value per kg (*i.e.,* of lower fibre diameter). The Dohne Merino (DM) has been featured as an alternative to address this issue. The breed was developed by the South African Department of Agriculture during the 1930s, and it was introduced to Uruguay in 2002, via Australia. The breed resulted from crossing Peppin Merino ewes with German Mutton Merino rams (McMaster, 2015). The DM is a dual-purpose breed with a good reputation as a meat and wool producer. The fineness of its wool (19 to 22 microns) constitutes an attractive feature. The latest information available indicates that DM represents about 3% of the Uruguayan flock (MGAP, 2018).

Abundant information about the performance of the DM breed has been generated in South Africa (Fourie and Heydenrych, 1983; Steinhagen and de Wet, 1986; van Wyk et al., 2008; McMaster, 2010). By contrast, the dissemination of the breed in Uruguay has not been accompanied by research on the adaptation of the breed to different areas, or on alternative breed roles. The use of the DM breed in crossbreeding programs has not been quantified and it has generally been part of an upgrading process of other breeds. The Uruguayan Wool Secretariat (SUL, for Secretariado Uruguayo de la Lana in Spanish) has conducted studies in commercial flocks, crossing DM with C and with Australian Merino (AM) (Abella and Preve, 2009; Preve and Abella, 2010). The most thorough work on the use of DM in Uruguay has been conducted by the National Institute for Agricultural Research (INIA, for Instituto Nacional de Investigación Agropecuaria in Spanish) (De Barbieri et al., 2021), comparing C, ½DM_½C, and ¾DM_¼C. In broad terms, DM crosses with C have shown lower fibre diameter and fleece weight, greater lamb growth rate and carcass yield, and better reproductive performance in ½DM_½C. Crosses of DM with Merino show variable results, depending on the strain of the latter breed, but they have generally shown lower fleece weight, little (greater) or no difference in fibre diameter, and superior growth rate and carcass attributes.

The research approach followed to date has visualized DM as a competitor of other, already established, maternal breeds in Uruguay. The effect of different fractions of DM genes has been explored, but without proposing a sustainable, ongoing, breeding strategy (apart from upgrading and breed replacement) to capture any benefits derived from the use of DM. An alternative approach, not yet investigated, is to consider DM as complementary to existing maternal breeds, particularly C. Because C and DM have not had common ancestors for a long time, it is reasonable to anticipate that crosses between C and DM may exhibit heterosis for some economically important traits. Rotational crossbreeding between C and DM offers the possibility of capturing two-thirds of the potential heterosis (Carmon et al., 1956). It is simple to implement and could therefore be attractive to producers. It has the great virtue of positioning both breeds as complementary, not as competitors, in the endeavour of producing more profitable sheep.

The objective of the present study was to evaluate wool and body traits of ewe hoggets generated during the establishment of a rotational crossbreeding scheme between C and DM. Hogget production is one of the earliest outcomes of a crossbreeding program. Outcomes at later ewe ages will be separately reported.

MATERIALS AND METHODS

The environment and production system

The experimental work was carried out in the Bernardo Rosengurtt Experimental Station (EEBR, for Estación Experimental Bernardo Rosengrutt in Spanish), Department of Cerro Largo (32°35’62’’S, 54°44’13’’W). The average maximum and minimum temperatures are 23 °C in January and 12 °C in June, respectively. The average annual rainfall from 1980 to 2009 was 1238 mm, evenly distributed during the year (Castaño et al., 2011; INUMET, 2019).

The area grazed by the experimental flock in the EEBR was about 150 ha. Except during mating and lambing, breeding ewes grazed as a single management group. After weaning, progeny also grazed as a single management group. Grazing was on native pastures characterized by herbaceous vegetation of a few grass species, low dry matter yields, and marked seasonal growth. Pasture production peaks in spring and summer when 60% of the annual dry matter production occurs (Carámbula, 1988). About 20% of the total area is occupied by sown pastures, *Avena sativa* L. (oats) and *Lolium multiflorum* (annual ryegrass), which are grazed during winter. Fifteen days before lambing, breeding ewes were given a supplement of ground rice husks at a rate of approximately 1% of live weight.

Flock management

Mating took place in autumn, from March 20 to May 10, whereas lambing was from late August to October. Rubber rings were applied to lambs at birth for tail docking, and to the scrotum in males, pushing testicles into the abdomen to induce cryptorchidism (PENRO, 2020). Lambs were marked in late October and weaned in the second half of December. Lambs were shorn after weaning to avoid fleece contamination and injuries caused during the flowering and maturing of some grass species (*Stipa* sp., common name 'flechilla'), which occurs in summer. At that stage, the male progeny was sent for slaughter or sold as trade lambs, whereas female lambs were kept as replacements.

Breeding ewes were shorn 4 to 6 weeks before the beginning of lambing in July or August, depending on weather conditions and shearers' availability. Young females (hoggets) were shorn in October when they were on average 415 days old, with 308 days of wool growth.

Breeding ewes were strategically drenched a week before mating, a week before the beginning of lambing, at lamb marking and at weaning. Ewe lambs were monitored for worm egg count (WEC) every three weeks during summer or as deemed necessary according to prevailing weather, pasture, and sheep conditions. Ewe lambs were tactically drenched if WEC exceeded 500. Health management practices included biannual vaccinations against clostridial diseases, preventive pour-on against lice and sheep scab at shearing, preventive foot-rot baths, and control of flystrike.

Experimental animals and mating design

The experiment began with 400 breeding ewes of the C breed. In 2015, 100 of the 400 ewes were mated to C rams, whereas the rest (300) were mated to DM rams. One-half of the resulting female crossbred progeny (½DM_½C) was mated to C rams, and the other half was mated to DM rams, thus initiating a rotational crossbreeding scheme. Simm et al. (2021) describe its application, whereas Carmon et al. (1956) give an account of the theory and prediction equations. This system simultaneously uses rams (or semen) of both breeds involved, so that crossbred females with a greater proportion of C genes are mated to DM rams, and vice versa. Two breeding flocks are established, one in which C rams are used, and the other one in which DM rams are used (Fig. 1). The crossbred females generated are used as replacements in the alternative flock from that in which they were born. Male progenies are not used for reproduction; in our study, they were sold as stores for slaughter, or as wethers for wool production.

C and DM rams were either purchased, donated by breeders of their respective breed

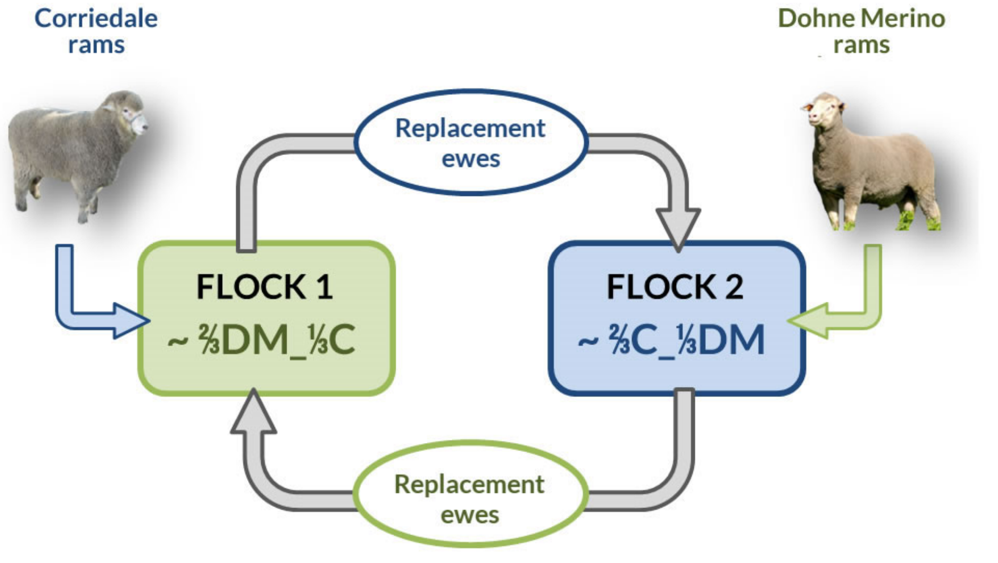

Fig. 1. Schematic representation of rotational crossbreeding between Corriedale and Dohne Merino.

societies, or obtained by exchange with another experimental station. In all instances, the rams used were approved and considered acceptable by representatives of their respective breed societies. The data analyzed in the present study were generated by 25 rams (13 C and 12 DM). Within each age group, females were randomly assigned to rams.

Data recording

Records were taken for progenies born from 2015 to 2020. Just before shearing, fleece rot (FR), wool colour (Co), wool character (Ch), and face cover (FC) were subjectively assessed using Version 2 of the Australian Visual Sheep Scores system (AWI and MLA, 2013). During shearing, greasy fleece weight (GFW) was recorded and a mid-side wool sample was taken and sent to the SUL wool laboratory for analysis and determination of scouring yield (Yld), average fibre diameter (FD), coefficient of variation of FD (CVFD), percentage of fibres with a diameter greater than 30 microns (F30) and staple length (SL). Live weight (PSLW) and conformation score (Conf; AWI and MLA, 2013) were recorded post-shearing.

Statistical analyses

The statistical model fitted to the data was as follows:

$$Y_{ijklmn} = \mu + G_i + S_j + (GS)_{ij} + Yr_k + TR_l + AoD_m + \beta\left(AgeShrng_{ijklmn} - \overline{AgeShrng}\right) + e_{ijklmn}$$

where Y is an observed value, μ is the overall mean, G_i is the effect of the ith genotype, S_j is the effect of the jth sire, *GS* is the interaction effect between *G* and *S*, *Yr* is the year effect of the kth year of birth, *TR* is the effect of the lth type of rearing, *AoD* is the effect of the mth age of the dam, *AgeShrng* is the age at shearing of the lamb, β is the regression coefficient of the trait in question on age at shearing, and *e* is the experimental error. All effects were treated as fixed except *S*, *GS*, and *e*, which were treated as random, and *AgeShrng*, which was fitted as a linear covariate.

In preliminary runs two-way interactions among the fixed effects were fitted but they were deleted from the model because they were non-significant or because they could not be fitted due to missing observations in some sub-classes.

SAS 9.4 software (SAS Institute Inc., 2013) was used to perform the analyses. PROC MIXED was used in the analysis of continuous data, whereas both PROC MIXED and PROC GLIMMIX were used to analyze scores for subjectively assessed traits. There were instances in which the analyses with PROC GLIMMIX did not converge or failed to produce sensible results due to non-positive definite matrices. When PROC GLIMMIX worked well, it produced results that were almost identical to those produced by PROC MIXED. For this reason, we present the results for scores from fitting a linear model with PROC MIXED for consistency and ease of interpretation.

Calculation of gross margins

Gross margins for each genotype were calculated following the methodology described in PIRSA (2021). Production (clean fleece weight and fibre diameter) values were based on the least squares means estimated in this study for each genotype. It was assumed that those two traits determined wool value.

Table 1 shows the assumed wool prices and variable production costs. The range in wool prices was provided by companies that currently market wool in Uruguay and by sheep production consultants (CLU, 2023; Unión de Consignatarios y Rematadores de Lana Del Uruguay, 2023). Variable costs are those that vary according to the level of production of the flock. Other costs (*e.g.*, taxes, levies, electricity, labour) were assumed to be independent of the production level of the flock (*i.e.*, fixed). Gross margins were calculated for each genotype for a hypothetical flock of 100 ewe hoggets. As there were some significant differences between genotypes in hogget live weight (*e.g.* ½DM_½C was heavier than C), we 'adjusted' the number of hoggets of all crosses to a stocking pressure equivalent to that of 100 C hoggets by assuming that hogget feed intake was proportional to PSLW$^{0.75}$ (Kleiber, 1975).

A SAS script (available from the senior author) was developed to perform the calculations. It can be used to explore scenarios other than those examined in the present study.

RESULTS

Table 2 shows descriptive statistics for all the traits recorded as well as details of the scoring system used for subjectively assessed traits.

For the presentation of the results and their subsequent discussion, we mainly focus on differences among genotypes. Other effects are not commented, except when they are of relevance to the genotype evaluation. Tables 3 and 4 show the analysis of variance and the least squares means, respectively, for wool and body traits subjectively assessed before (FR, Co, Ch, FC) or after shearing (Conf). There were no significant differences among genotypes for FR, Co, and Conf, but there were for Ch and FC. Genotypes with a greater proportion of DM genes

Table 1. Wool prices and variable production costs in United States of America dollars (US$).

Item	**Value (US$)**											
Genotype*	⅝DM_⅜C		⅝C_⅜DM		¾DM_¼C		¾C_¼DM		½DM_½C		C	
Assumed fibre diameter (µm) for each genotype**	20.0		21.8		19.9		22.0		21.4		23.5	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Low and high wool prices for each genotype												
Clean wool (US$/kg)	5.50	7.47	4.70	6.63	6.70	7.52	4.50	6.41	4.80	6.91	3,00	4.61
Variable cost												
Shearing, conditioning, bagging (US$/animal)	2.50		2.50		2.50		2.50		2.50		2.50	
Wool packs (US$/kg of wool harvested)	0.0625		0.0625		0.0625		0.0625		0.0625		0.0625	
Vaccines (US$/animal)	0.33		0.03		0.03		0.03		0.03		0.03	
Anthelmintics (US$/animal)	0.60		0.60		0.60		0.60		0.60		0.60	
Dipping, lice, fly strike treatments (US$/animal)	1.44		1.44		1.44		1.44		1.44		1.44	

* Crossbred ewe hoggets with different proportions of Corriedale (C) and Dohne Merino (DM), and purebred C.
** Based on least squares means (Table 6).

had a lower Ch score, indicating greater crimp definition. Genotypes with a greater proportion of C genes had a greater FC score, indicating the presence of more wool on their face.

Tables 5 and 6 show the analysis of variance and least squares means, respectively, for objectively measured wool and body traits. There were significant differences among genotypes for all traits. For GFW, Yld, CFW, FD, CVFD, and F30 genotypes with a greater proportion of C had higher values. The pattern for PSLW is less clear. Pure C had the lowest value, but it did not significantly differ from the other genotypes, except for ½DM_½C. The latter genotype had the highest value but it only differed significantly from C and ¾DM_¼C.

Table 7 shows the gross margins for each genotype assuming a flock size of 100 ewe hoggets. Gross margins varied across genotypes and wool prices. When no adjustment was made for the greater intake of heavier animals, ¾DM_¼C ewe hoggets had the greatest GM at a low wool price, whereas ½DM_½C had the greatest GM at a high wool price. The GMs of ⅝DM_⅜C and ⅝C_⅜DM were similar to each other for both low and high wool prices. Purebred C had the lowest GM at both low and high wool prices. When adjustment was made for the greater intake of heavier hoggets, the pattern remained unchanged, GMs were slightly reduced in the crosses, but they remained well above that for C.

DISCUSSION

Wool production and body traits

The results for wool production are consistent with the background of the breeds involved in this study. C and DM are dual-purpose breeds that produce fibre of widely different diameters, but both breeds have years of selection on traits such as FR and Co, hence the non-significant differences among genotypes for these traits. The differences found for Ch, where genotypes with a greater proportion of C had higher scores, are consistent with the fact that greater fibre diameters are generally associated with a less defined crimp (Doyle et al., 2021) (Tables 4 and 6).

Purebred C had the highest score for FC, followed by genotypes with a higher proportion of C. The opposite was true for genotypes with a higher proportion of DM. This observation is consistent with the standard of each breed, where some degree of FC is sought in C, whereas fully open faces are favoured in DM (SCCU, 1952; ADBA, 2018; Gimeno et al., 2019). The FC score observed in both C and its crosses with DM in the present study is unlikely to require wigging in many individuals, which would entail an

Table 2. Descriptive statistics: number of observations (N), simple mean, minimum and maximum, standard deviation (σ) and coefficient variation (CV, %).

	N	Mean	Min	Max	σ	CV
Pre-shearing subjectively assessed wool quality and body traits *						
Fleece rot (FR)	843	2.54	1.00	5.00	1.31	51.7
Wool colour (Co)	843	2.97	1.00	5.00	0.69	23.2
Wool character (Ch)	843	2.91	1.00	5.00	0.99	33.9
Face cover (FC)	727	3.01	1.00	5.00	0.78	25.8
Objectively measured wool quality traits						
Greasy fleece weight (GFW, kg)	847	2.82	1.35	4.85	0.66	23.5
Scouring yield (Yld, %)	846	75.5	58.1	92.6	4.63	6.13
Clean fleece weight (CFW, kg)	846	2.12	1.07	3.70	0.48	22.8
Fibre diameter (FD, μm)	846	21.7	15.6	30.5	2.20	10.1
Coefficient of variation (CV) of FD (CVFD, %)	846	22.7	14.3	32.9	3.17	14.0
Percentage of fibres greater than 30 μm in diameter (F30)	846	6.47	0.10	46.5	6.56	101
Staple length (SL, cm)	846	8.89	5.50	14.5	1.52	17.1
Post-shearing objectively measured or subjectively assessed body traits						
Live weight (PSLW, kg)	844	33.7	20.0	64.5	7.22	21.7
Conformation* (Conf)	728	1.76	1.00	5.00	1.12	69.7

* Based on the scoring system of the Australian Wool Innovation and Meat and Livestock Australia, Visual Sheep Scores (AWI and MLA, 2013).
Fleece rot score: 1 = no bacterial colouring or staining, ..., 5 = band of crusting > 5 mm wide with or without bacterial staining; wool colour: score: 1 = the brightest white wool, ..., 5 = yellow; wool character score: 1 = well-defined crimp along the entire length of the staple, ..., 5 = large areas of ‘flat’ wool lacking in crimp definition; face cover score: 1 = open face with no wool on the jowls or top of the head, ..., 5 = wool covering the entire face; conformation (based on shoulder/back score): 1 = angular shoulders and straight back between the top of the shoulder blades and hips, ..., 5 = shoulder blades that sit above (or below) the spine to create an extremely ‘dipped’ backline.

additional cost. Assuming that only those with a score of 5 would require wigging, this category represented about 5% of the recorded sheep, out of which there were approximately twice as many purebred C when compared to DM crosses.

The results for the objectively assessed wool traits were also consistent with the background of both breeds. The lower GFW and CFW of genotypes with a greater proportion of DM reflect the historically defined breeding objective for the breed (McMaster, 2016; ADBA, 2023). In DM breeding, a balance was sought between clean fleece weight and live weight, in which the favoured ratio between these two variables (expressed as wool production potential, WPP%, Herselman et al., 1998) was 5 to 6%. In our case, the ratio CFW/PSLW (Table 6) for the genotype with the greatest proportion of DM (¾DM_¼C) was 5.6%, well within the above-mentioned range. By contrast, it was 7% for purebred C. The pursuit of a 5 to 6 WPP% in DM provides a plausible explanation for its lower GFW and CFW compared with other Merino strains bred without that constraint (Van der Merwe et al., 2020), or with C (De Barbieri et al., 2021). The latter study reports the upgrading of C by DM, where the reduction of fleece weight as the proportion of DM increased is evident. Yld decreased in the same manner.

The values for FD, CVFD, and F30 were lower for genotypes with a greater proportion of DM. In contrast with fleece weights, this constitutes an advantage because lower values are associated with better processing performance and product quality (*i.e.*, comfort when a garment is worn directly on the skin) (Schlink, 2017; Cardellino and Trifoglio, 2022; Mamani-Cato et al., 2022). These features associated with lower FD are the reason for the higher prices paid for finer wools.

Genotype ½DM_½C had the highest PSLW, but it only differed significantly from C and ¾DM_¼C. Pure C had the lowest value, but it did not significantly differ from the other genotypes, except for ½DM_½C. De Barbieri et al. (2021) report that genotype ¾DM_¼C had the highest live weight, slightly ahead of ½DM_½C, but both were well above pure C. Although not in perfect agreement, De Barbieri’s and our study confirm that crossing C with DM will improve growth rate and live weight. We found no significant differences among genotypes in subjectively assessed Conf. However, in a thorough examination of carcass

Table 3. Analysis of variance for subjectively assessed wool and body traits*: fleece rot (FR), wool colour (Co), wool character (Ch), face cover (FC), and conformation (Conf).

Effect	FR				Co				Ch				FC				Conf			
	Ndf	Ddf	F-val.	p > F	Ndf	Ddf	F-val.	p > F	Ndf	Ddf	F-val.	p > F	Ndf	Ddf	F-val.	p > F	Ndf	Ddf	F-val.	p > F
Genotype	5	26	0.95	0.47	5	26	0.80	0.56	5	26	4.06	<.01	5	26	9.34	<.01	5	26	0.61	0.70
Year of birth	5	751	14.0	<.01	5	751	0.94	0.45	5	751	29.8	<.01	4	640	27.6	<.01	4	641	191	<.01
Rearing type	1	751	2.51	0.11	1	751	4.66	0.03	1	751	0.06	0.81	1	640	1.43	0.23	1	641	0.32	0.57
Age of dam	3	751	0.65	0.58	3	751	1.43	0.23	3	751	2.78	0.04	3	640	1.13	0.33	3	641	0.88	0.45
Age of shearing	1	751	3.10	0.08	1	751	1.39	0.24	1	751	2.49	0.12	1	640	2.12	0.15	1	641	0.10	0.75
Residual		1.52				0.46				0.71				0.37				0.35		

Ndf: numerator degrees of freedom, Ddf: denominator degrees of freedom.

* Based on the scoring system of the Australian Wool Innovation and Meat and Livestock Australia, Visual Sheep Scores (AWI and MLA, 2013).

traits, De Barbieri et al. (2021) found that DM crosses generally outperformed pure C.

An individual sheep producer may consider that the relative physical performance of pure C and the various DM crosses is insufficient to make a decision (*i.e.*, pure C has a higher fleece weight, but the wool it produces is of greater fibre diameter and lower value; DM crosses may be heavier than pure C but that may bring about greater nutritional needs per animal). In such cases, the calculation of gross margins can be useful because it integrates physical performance, product values, and production costs, thus allowing a comparison of genotypes in monetary units (Roa, 2012; Ceballos et al., 2021; PIRSA, 2021).

Gross margins

Table 7 summarises the gross margins calculated considering the wool prices and production costs shown in Table 1. It presents values without and accounting for the likely increase in feed requirements due to the greater live weight of some genotypes. The main feature of Table 7 is that, irrespective of wool price (low or high), or whether the gross margins are not or are adjusted for the possible greater feed requirements of heavier hoggets, pure C has the lowest GM. There are differences among genotypes with different proportions of DM, but these are smaller than between C and any other genotype. Because DM crosses were heavier than C, their advantage over the latter genotype was reduced when the adjustment for their greater live weight was made. However, the reduction was small and the advantage over C remained substantial.

In practical terms, this means that a sheep producer using a rotational crossbreeding scheme between C and DM should expect an increase in the GM resulting from ewe hoggets right from the beginning of the program. Note that in our calculations we assumed that C wool could be sold, albeit at a lower price than finer wools. Fibre diameter is likely to increase with age; in our experimental flock at the EEBR adult C ewes have an average FD of about 28.4 microns. During the past few seasons, wool of that fineness has been, at best, extremely difficult to market, and some producers have a backlog of unsold wool (El Observador, 2022; Aldabe, 2023). This scenario would exacerbate the difference in GM between DM crosses and C because unsold wool represents a net loss for the producer. Note that although the FD of wool from DM crosses will also increase with age (*i.e.*, to 23.5 microns in our EEBR); it is more likely to remain within a marketable range.

Table 4. Least squares means (standard errors) for subjectively assessed wool and body traits*: fleece rot (FR), wool colour (Co), wool character (Ch), face cover (FC), and conformation (Conf).

Effect - Level	FR	Co	Ch	FC	Conf
*Genotype***					
⅝DM_⅜C	2.30 (0.33)	2.76 (0.19)	2.28a (0.24)	2.68c (0.17)	1.70 (0.16)
⅝C_⅜DM	2.48 (0.35)	3.14 (0.20)	2.60ab (0.25)	3.18ab (0.18)	1.69 (0.17)
¾DM_¼C	2.56 (0.15)	2.94 (0.09)	2.66a (0.13)	2.70c (0.09)	1.75 (0.06)
¾C_¼DM	2.47 (0.15)	2.95 (0.09)	3.04b (0.13)	3.12b (0.09)	1.73 (0.06)
½DM_½C	2.51 (0.13)	2.93 (0.07)	3.15b (0.11)	2.88bc (0.08)	1.63 (0.06)
C	2.24 (0.13)	2.85 (0.08)	3.07b (0.11)	3.43a (0.08)	1.63 (0.06)
Year of birth					
2015	2.93ad (0.20)	2.78 (0.11)	2.81a (0.16)	3.45a (0.12)	3.67 (0.10)
2016	1.94bc (0.21)	2.88 (0.12)	2.98ab (0.16)		
2017	2.60ad (0.17)	2.89 (0.09)	2.81a (0.13)	3.22b (0.09)	1.74 (0.08)
2018	2.86a (0.19)	3.04 (0.11)	2.94a (0.14)	3.23ab (0.10)	1.01a (0.09)
2019	1.79b (0.15)	2.92 (0.08)	1.94 (0.12)	2.51c (0.08)	1.04a (0.07)
2020	2.42cd (0.15)	3.05 (0.09)	3.32b (0.12)	2.58c (0.08)	0.96a (0.07)
Rearing type					
1	2.53 (0.11)	3.01a (0.06)	2.79 (0.09)	3.04 (0.06)	1.71 (0.04)
2	2.32 (0.16)	2.85 (0.09)	2.81 (0.12)	2.96 (0.09)	1.67 (0.07)
Age of dam					
2 years	2.49 (0.13)	2.84 (0.07)	2.88a (0.10)	3.02 (0.07)	1.69 (0.06)
3 years	2.40 (0.14)	2.93 (0.08)	2.91a (0.11)	3.04 (0.08)	1.64 (0.07)
4 years	2.33 (0.15)	3.00 (0.09)	2.75ab (0.12)	2.92 (0.08)	1.68 (0.07)
5 or more years	2.48 (0.15)	2.93 (0.08)	2.65b (0.11)	3.01 (0.08)	1.75 (0.07)

Between levels, for each source of variation, least squares means without a common superscript differ significantly ($p < 0.05$).

* Based on the scoring system of the Australian Wool Innovation and Meat and Livestock Australia, Visual Sheep Scores (AWI and MLA, 2013).

** Crossbred ewe hoggets with different proportions of Corriedale (C) and Dohne Merino (DM), and purebred C.

In general, our results were consistent with those of De Barbieri et al. (2021) and showed that despite the trade-off between C (high fleece weight but depressed wool value) and DM (low fleece weight but favourable wool value), the balance is in favour of crossing. The proposed rotational crossbreeding scheme offers the opportunity to maintain a greater GM over time. Moreover, there are ways in which the benefits derived from crossing C with DM could be increased. In our study, both C and DM rams used were approved by their respective breed associations, but not deliberately genetically selected in any other way, and there was no culling among the ewe progeny generated. The economic worth of the crossbred hoggets could be increased if C rams were selected based on breeding values predicting lower than average FD while not compromising CFW, and if, in contrast, DM rams were selected based on breeding values predicting higher than average CFW while not compromising FD. If the flock's reproductive rate was high enough to allow culling among the ewe progeny generated, a simple selection index could be used, aimed at maximizing profit from wool sales.

Notwithstanding the benefits producers can obtain from the establishment of a rotational crossbreeding scheme between the C and DM breeds, such benefits would be greater if a source of sheep had both high fleece weight and low fibre diameter. A preliminary (and unfortunately discontinued) trial using a dual-purpose AM ram over DM ewes showed that first cross hoggets had an average greasy fleece weight 900 g heavier than purebred DM while having the same fibre diameter (17 μm) and scouring yield (74%) (Abella, 2020). Note that this difference in fleece weight is greater than that observed between C and its crosses with DM in the present study. The AM progeny had higher live weight at weaning and as hoggets, while their carcasses had a greater eye muscle area and the same fat cover as pure DM (Abella, 2020). This means that, when crossed with C, suitable Merino sheep

Table 5. Analysis of variance for greasy fleece weight (GFW), scouring yield (Yld), clean fleece weight (CFW), fibre diameter (FD), coefficient of variation of FD (CVFD), percentage of fibres with a diameter greater than 30 µm (F30) and post-shearing live weight (PSLW).

Effect	Ndf	GFW			Yld			CFW			FD			CVFD			F30			PSLW		
		Ddf	F-val.	p > F	Ddf	F-val.	p > F	Ddf	F-val.	p > F	Ddf	F-val.	p > F	Ddf	F-val.	p > F	Ddf	F-val.	p > F	Ddf	F-val.	p > F
Genotype	5	26	10.7	<.01	26	6.47	<.01	26	14.9	<.01	26	27.3	<.01	26	6.22	<.01	26	27.0	<.01	26	4.15	0.01
Year of birth	5	758	149	<.01	757	28.9	<.01	757	108	<.01	757	20.4	<.01	757	12.9	<.01	757	13.6	<.01	752	269	<.01
Rearing type	1	758	11.2	<.01	757	0.88	0.35	757	12.6	<.01	757	0.18	0.67	757	1.97	0.16	757	3.72	0.05	752	6.10	0.01
Age of dam	3	758	0.82	0.48	757	0.67	0.57	757	0.58	0.63	757	0.67	0.57	757	1.08	0.36	757	1.19	0.31	752	1.20	0.31
Age of shearing	1	758	5.86	0.02	757	2.75	0.10	757	7.90	0.01	757	18.8	<.01	757	0.51	0.47	757	9.05	<.01	752	5.06	0.02
Residual			0.13			14.6			0.08			2.44			6.92			24.1			11.6	

Ndf: numerator degrees of freedom, Ddf: denominator degrees of freedom.

may reduce FD, without entailing a loss in fleece weight and even result in a gain in that trait. This would imply that the advantages of crossing C with a fine wool genotype such as that used in Abella's (2020) work would be even greater than those identified in the present study.

CONCLUSIONS

The proposed rotational crossbreeding scheme between C and DM should be an attractive proposition for C producers. It would rapidly enhance their income from wool without altering the good meat-producing attributes of the C breed. The strategy offers an option to those producers who wish to add value to their wool and increase the profitability of their flock, without abandoning the C, a breed in which they have placed their trust for many years. The advantage could be even greater by implementing some simple selection strategies, or if a source of AM rams were found that reduced FD, without the loss in fleece weight that the use of DM entails. This work was focused on the Uruguayan sheep production scenario, but the results apply to neighboring countries such as Argentina and Chile, where C and DM are present, or southern Brazil where C has been an important breed.

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Table 6. **Least squares means (standard errors) for greasy fleece weight (GFW), yield (Yld), clean fleece weight (CFW), fibre diameter (FD), coefficient of variation of FD (CVFD), percentage of fibres with a diameter greater than 30 μm (F30) and post shearing live weight (PSLW).**

Effect - Level	GFW	Yld	CFW	FD	CVFD	F30	PSLW
*Genotype**							
⅝DM_⅜C	2.52a (0.10)	73.7ad (1.05)	1.85a (0.08)	20.0a (0.46)	20.9a (0.79)	2.37ab (1.40)	33.1ab (0.95)
⅝C_⅜DM	2.85b (0.10)	75.1abcd (1.08)	2.12b (0.08)	21.8b (0.47)	22.4ab (0.79)	5.35bc (1.43)	32.6ab (1.00)
¾DM_¼C	2.46a (0.05)	73.6a (0.51)	1.80a (0.04)	19.9a (0.26)	20.9a (0.43)	1.81a (0.72)	32.1a (0.45)
¾C_¼DM	2.80b (0.05)	76.2c (0.51)	2.12b (0.41)	22.0b (0.25)	23.3b (0.42)	7.23c (0.72)	32.2ab (0.45)
½DM_½C	2.80b (0.05)	75.6cd (0.44)	2.11b (0.04)	21.4b (0.23)	22.7b (0.38)	5.83c (0.64)	33.5b (0.37)
C	2.85b (0.05)	77.2b (0.45)	2.19b (0.04)	23.5 (0.23)	23.7b (0.38)	11.8 (0.64)	31.3a (0.38)
Year of birth							
2015	2.31a (0.07)	76.8 (0.65)	1.77a (0.05)	21.0b (0.30)	21.3a (0.50)	3.91bc (0.89)	28.5a (0.58)
2016	2.11 (0.07)	80.4 (0.68)	1.69a (0.05)	20.8b (0.30)	20.0 (0.50)	3.07b (0.91)	28.3a (0.60)
2017	2.87 (0.05)	73.8a (0.54)	2.12 (0.04)	21.6 (0.25)	21.8a (0.40)	5.34c (0.73)	28.6a (0.46)
2018	3.57 (0.06)	73.2a (0.62)	2.61 (0.05)	22.5a (0.29)	22.8 (0.45)	8.71 (0.83)	45.0 (0.52)
2019	3.08 (0.05)	73.1a (0.49)	2.26 (0.04)	22.3a (0.23)	23.6 (0.37)	8.45a (0.67)	33.7 (0.40)
2020	2.33a (0.05)	74.1a (0.51)	1.73a (0.04)	20.5b (0.24)	24.5 (0.38)	5.04abc (0.69)	30.8 (0.41)
Rearing type							
1	2.78a (0,04)	75.4 (0.36)	2.09a (0.03)	21.4 (0.18)	22.1 (0.28)	5.25 (0.50)	32.9a (0.29)
2	2.65 (0,05)	75.0 (0.50)	1.98 (0.04)	21.5 (0.23)	22.5 (0.37)	6.26 (0.67)	32.0 (0.43)
Age of dam							
2 years	2.71 (0.04)	75.6 (0.43)	2.04 (0.03)	21.3 (0.20)	22.5 (0.32)	5.63 (0.58)	32.1 (0.36)
3 years	2.68 (0.05)	75.3 (0.47)	2.01 (0.04)	21.5 (0.22)	22.5 (0.35)	6.31 (0.63)	32.2 (0.40)
4 years	2.73 (0.05)	75.0 (0.49)	2.04 (0.04)	21.4 (0.23)	22.2 (0.37)	5.75 (0.67)	32.8 (0.42)
5 or more years	2.74 (0.05)	75.1 (0.48)	2.05 (0.04)	21.4 (0.22)	22.1 (0.36)	5.32 (0.64)	32.7 (0.41)

Between levels, for each source of variation, least squares means without a common superscript differ significantly ($p < 0.05$).
* Crossbred ewe hoggets with different proportions of Corriedale (C) and Dohne Merino (DM), and purebred C.

Table 7. Gross margin (GM) in United States of America dollars (US$) for a flock of 100 crossbred ewe hoggets with different proportions of Dohne Merino (DM) and Corriedale (C), and for purebred C.

Genotypes*	Gross margin (US$)			
	Low wool price		High wool price	
	NA**	A	NA	A
⅝DM_⅜C	515	494	879	843
⅝C_⅜DM	492	478	901	875
¾DM_¼C	704	691	851	987
¾C_¼DM	450	440	854	836
½DM_½C	508	483	954	908
C	152	152	503	503

* Crossbred ewe hoggets with different proportions of Corriedale (C) and Dohne Merino (DM), and purebred C.
** NA: not adjusted for post-shearing live weight; A: adjusted for post-shearing live weight.

Authors' contributions

All authors contributed equally to the conception and writing of the manuscript. All authors critically revised the manuscript and approved the final version.

Bioethics and biosecurity committee approval

We declare that all aspects of this manuscript referring to animal management were carried out following the Guide for the ethical production of sheep in Uruguay and with the ethical approval of all relevant agencies.

Declaration of conflict of interest

The authors declare no conflict of interest. The funding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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