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Sheep production systems in Chilean Patagonia. Characterization and typology

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ABSTRACT

Sheep production is a common activity in family farms that develop mixed farming in developing countries in South America. In the area known as the Patagonia, it is possible to find this type of farm in isolated areas with a temperate climate, where sheep production takes place in small and medium-sized flocks managed with family labor. In these systems, obtaining animal protein for family consumption and the sale of surpluses is the main objective of farmers. The Chilean Patagonia is an area that stands out for its tourist attractions. This feature has been used at the government level to develop production and commercial linkage and improvement programs. However, the proper application of these programs needs to characterize sheep production systems, define groups, determine similarities and differences among them, and identify individual or joint adaptation strategies. Thus, the objective of this research was to characterize sheep farming in an extreme mountain area in the Chilean Patagonia and provide a typology of sheep production systems, focusing on the socio-productive aspects of family farms. Within the province of Palena, the study area corresponded to the communities of Palena and Futaleufú, where a survey was given to a sample of 172 sheep farmers. Through multivariate analysis methodologies, four groups of sheep production systems were identified. The main differences between systems were farm surface, surface destined for sheep, type, duration, and supplementation strategy and presence of purebred sheep. Sheep production in extreme areas contributes to rural families' livelihood by being part of an integrated system of activities that naturally uses circular economy strategies and sustainable practices. Geographical isolation limits the marketing channels, generating that the surpluses produced are sold locally. Given the government strategies to support the study area and the strong tourist component of governmental assistance, the sheep farmers need to modify their management strategies.

1. Introduction

A family farm can be defined as a complex unit of animals, and crops that, in an interrelated way, positioned on small properties and with little investment in capital and limited use of external labor, obtain a regular supply of food and adequate income (Kuivanen et al., 2016). These farms generally carry out a type of mixed agriculture where livestock and crops are usually integrated (Olaizola et al., 2015; Behera and France, 2016). Among the animal species characteristic of this type of farms are dual-purpose bovines, small ruminants, poultry, and pigs (Bertolozzi-Caredio et al., 2020). In Mediterranean areas of Spain and Chile, a large part of the farms, where sheep are located correspond to a typical example of this type of family farm (Toro-Mujica et al., 2015; Riveiro et al., 2013). However, in temperate climates in the south of Chile, specifically in the Los Lagos Region, it is also possible to find this type of family farm where 97 % of the farmers own less than 60 sheep (INE, 2007). These farms are managed under a pastoral system and are focused on producing lambs for self-consumption and sale. Self-consumption is a traditional practice in the small ruminant production system, valued as a subsistence strategy and encouraged to search for food security in underdeveloped countries (Wodajo et al., 2020; del Valle et al., 2019). As Wodajo et al. (2020) points out, farmers relate the presence of sheep with the four dimensions underpinning food security: accessibility, availability, nutritional value and stability. Small ruminants are among the most popular and beneficial livestock for producers with very limited resources having a very significant impact on their income, social status and even on the local environment (De Vries, 2008). Thereby, small ruminant production systems provide a

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source of high-quality protein and can improve sustainability as well as employment and income generation opportunities in rural areas (Escareño et al., 2013; Peacock, 2005; Valdivia, 2001). The lambs' surpluses produced in family farms are sold locally, being a commonly observed practice the sale of live animals at the farm gate. In most cases, this allows obtaining better prices for the farmer, since this sale is direct to the consumer, avoiding the loss of profit margin associated with intermediaries (Toro-Mujica et al., 2019a, 2019b; Kocho et al., 2011). On the other hand, as in the Mediterranean, semi-arid, and arid climates (Rosa and Bryant, 2003), sheep systems in temperate climates are highly seasonal, respecting natural cycles and, therefore, providing a discontinuous supply of products (Texeira et al., 2008). However, geographic isolation is a particular characteristic of sheep farms in temperate climates that determines the structure of the production system and conditions the farms' subsistence. In this territory, known as the Chilean Patagonia, geographical barriers hinder aspects, such as access to marketing channels, hiring labor, technology, genetics, and technical advice, that reduce the growth and modernization of the sheep production. Although the decrease in sheep stocks in recent decades has, indeed, been a trend on a global scale, observed in countries such as Spain, Norway, China, among others (Flaten, 2017; Morris, 2017; Li et al., 2015; Boutonnet, 1999), geographic isolation accentuates this decline. Thus, in Chile, the sheep census registered a decrease of 15.2 % between 2007 and 2013, dropping from 2.9 million to 2.4 million head (ODEPA, 2013; INE, 2007). In the Los Lagos Region, the decrease reached 31.2 %. As Toro-Mujica et al. (2019a, 2019b) and Estevez-Moreno et al. (2019) found, the evolution, adaptation strategies, or disappearance of the livestock production within a farm depends on the variables that define the farm and the interrelationships between them. That is on the typology of the production system. Thus, the objective of this research was to characterize sheep farming in an extreme mountain area in the Chilean Patagonia and provide a typology of sheep production systems, focusing on the socio-productive aspects of family farms.

2. Materials and methods

2.1. Study area

The study area for this research is located in the Los Lagos Region (parallels 40° 13′ and 44° 3′ of South latitude and between meridians 74° 49′–71° 34′ of W longitude), the beginning of the Chilean Patagonia, specifically in the Province of Palena, encompassing two of its four communities (Fig. 1): Futaleufú and Palena. Futaleufú, the smallest in the province of Palena, has a surface area of 1280 km^2, representing 8.3 % of the provincial area. The community of Palena is the southernmost in the province and has an area of 2764 km^2. In this mountain area, the climate, according to the Köppen classification, corresponds to temperate oceanic (Cfb) and includes two variants, the coastal area, and the Andean highlands. The study area is located in the Andean highlands, presenting an annual rainfall close to 2,000 mm and average temperatures between 9 and 11°C (Santibañez et al., 2017).

The communities of Palena and Futaleufú have historically presented geographic isolation arising from the lack of land connectivity. This unique feature conditions both the community's lifestyle and the typology of sheep production systems. The main connection is the maritime through the port of Chaitén. This absence of connectivity has resulted in a low total population in the study area (Palena: 1711 inhabitants; Futaleufú: 2623 inhabitants), resulting in an extremely low population density (Palena: 0.6 inhabitants/km^2; Futaleufú: 1.2 inhabitants/km^2) (INE, 2017). On the other hand, in these communities, rural families are predominant. Thus, while in the Los Lagos Region, the rural population reaches 26.4 %, in the communities under study, the rural population exceeds 65 % (INE, 2017).

Due to the difficulty of integrating the province of Palena nationally, the Chilean government has designated the area as an Extreme Zone while providing the province with special incentive plans and national policies to promote its development (BCN, 2010). As a result, in addition to the natural beauty of the area and the creation of the *Special Plan for Extreme Zones "Patagonia Verde"* (Green Patagonia), this area has developed into a tourist attraction and circuit with the goal of attracting more visitors and travelers (CORFO, 2018; GORE Los Lagos, 2018).

In the Los Lagos Region, according to the latest agricultural census, 30,335 farms have livestock. The average surface area is 51.4 ha. However, wide variability exists between farms (Standard deviation: 300.1). Thus, 93 % of the farmers own less than 100 ha. Within the total number of farmers, 64 % (19,074 farms) own sheep, with an average farm area and flock size of 43.7 ha and 17 sheep, respectively. This is related to the predominance of family sheep farms in the region (INE, 2007). In the communities of Palena and Futaleufú sheep farms totaled 138 and 150, respectively (INE, 2007). On these farms, the main objective for having sheep is the intra-farm consumption of the animals. However, as the flock grows, surpluses are generated that are marketed (lambs and sheep culled), as well as, in some cases, wool and leather. It is common for producers owning over 50 animals for them to shear their sheep for the wool. Farmers with fewer animals do not shear their sheep. Sanitary and nutritional management are generally scarce since the flock tends to remain under a continuous grazing system, with free access to wooded and scrub areas (INIA, 2019). With regard to soil resources, in the province of Palena, more than 70 % of the soils are not suitable for agricultural or forestry purposes. Pasture production varies between 2–6 tons Dry Matter/ha/year and, therefore, favors sheep farming (Iraira et al., 2017).

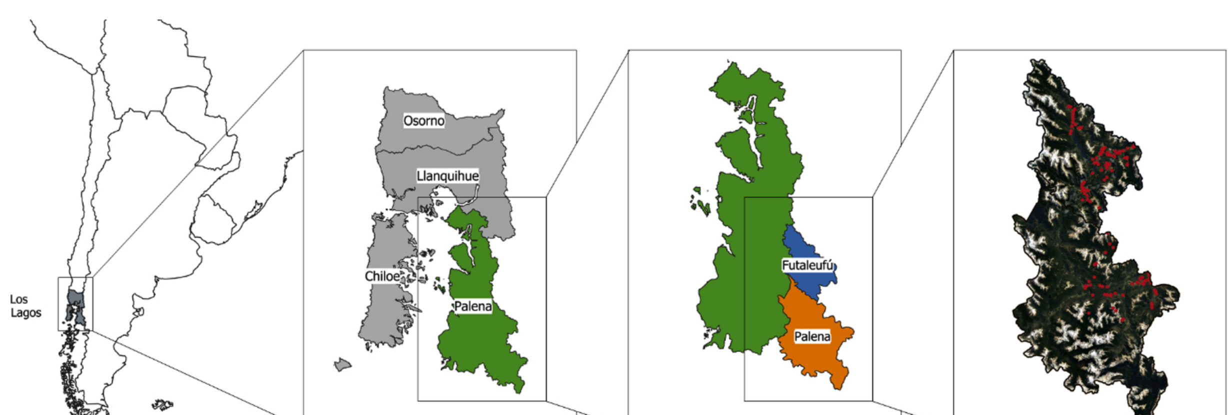

Fig. 1. Location of the communities of Palena and Futaleufú and the farms surveyed.

2.2. Survey

A survey with 123 questions was designed for obtaining data from the farmers about their farms. Of the total questions, 40 were open-ended and 83 closed. The survey was organized into 4 sections: livestock, farm, sheep production, infrastructure, and equipment. Within the sheep production section, aspects related to the size of the flock, management, breeds, feed resources, use and sale of products, and marketing channels were incorporated. The sampling was directed/intentional, considering inclusion criteria, the existence of surplus lambs, and that sheep production corresponded to one of the first three sources of income from the farm. The sampling objective was to survey at least 50 % of sheep farms in each of the two communes. In order to conduct face-to-face surveys, a student in the final year of agronomy was trained about the specific terminologies and contents for sheep production systems of the study region. The student was specializing in animal production. Contact with the farmers was made through technicians from the *Local Development Program* (*PRODESAL*) of each community. The duration of each survey was between 30 and 60 min. The surveys were carried out during June, July, and August 2018. The location of each farm was georeferenced with GPS (Global Positioning System) under the UTM (Universal Transverse Mercator) coordinate system and Google Earth® software.

2.3. Characterization and multivariate analysis

To characterize the farms surveyed, the variables obtained were grouped into quantitative and qualitative. In the quantitative variables, averages and standard deviations were obtained. In the qualitative variables, percentages were obtained (Toro-Mujica et al., 2015, 2020).

In order to identify groups of farmers, a multivariate analysis was carried out. For this, the methodology of multivariate analysis proposed by Escobar and Berdegué (1990) and carried out by Toro-Mujica et al. (2015, 2020) and Riveiro et al. (2013) was used. This methodology included four stages: 1. selection of variables, 2. principal component analysis, 3. cluster analysis, and 4. discriminant analysis. From the survey questions, the information was processed to obtain variables. Subsequently, the variables selection process was carried out, the coefficient of variation (CV $\geq$ 50 %) and the correlation coefficient were using as selection criteria. Regarding the correlation coefficient, a correlation matrix was developed to eliminate all the uncorrelated variables ($p \leq 0.05$) and select one of each pair of variables with correlations more significant than 90 %. In the principal component analysis, Bartlett's chi-square test was used to ensure adequate correlations, and the Kaiser–Meyer–Olgin index was used to determine sampling adequacy (Toro-Mujica et al., 2015; Uriel and Aldas, 2005). The selection of the principal components was based on the criterion of the eigenvalue ($\geq$1). Principal components selected were used in the subsequent cluster analysis (Gelasakis et al., 2017). A hierarchical cluster analysis was used to separate farms into distinct groups, using the Ward and centroid methods to delimit them. The Euclidean, square Euclidean, and Manhattan distances were estimated for each method. The elbow rule was used to select the adequate number of clusters (Gelasakis et al., 2012). Selected groups were tested using discriminant analysis. Subsequently, for comparing quantitative variables between groups of farms, analysis of variance (ANOVA) and multiple comparison of means (Student–Newman–Keuls) or Kruskal–Wallis, depending upon the homogeneity of the variances (Levene test), were conducted (Escribano et al., 2016). The comparison of qualitative variables between groups was made through contingency tables and chi-square tests (Toro-Mujica et al., 2020).

3. Results and discussion

3.1. Farm characterization

A total of 172 surveys were carried out, 74 in the community of Palena (43 %) and 98 in Futaleufú (57 %), representing 65 % and 54 % of the population of sheep farms in each area studied. The location of each of the surveyed farms and the two communities are shown in Fig. 1.

Of the total farms surveyed, 65 % were managed by men. This percentage was similar to that observed by Toro-Mujica et al. (2019a, 2019b) in sheep farms in the semi-arid zone of Central Chile. The average age was 57.5 $\pm$ 14.7 years, with no difference between men and women (Table 1). The average age recorded was similar to that reported by Estevez-Moreno et al. (2019) in three of the groups identified in sheep production systems in the community of Ojo de Agua in Mexico. Of the total number of farmers surveyed, more than 45 % were older than 60 years. The aging of sheep farmers is an increasingly common feature on a global scale, given the increasing decline in sheep farms associated with both the low profitability of sheep production and rural-urban migration of the young population (Toro-Mujica et al., 2019a, 2019b; Olaizola et al., 2015; Caballero and Fernández-Santos, 2009; MacDonald et al., 2000).

With regard to land ownership, in this study, 84 % of the farmers were owners, a higher percentage in the case of women (Table 2). In 68 % of the farmers, the level of education was primary school (completed or incomplete), and 6 % did not have any formal studies (Table 3). It was not possible to determine a relationship between the education level and the gender of the farmer (Table 2). This level of education was low compared to the 10.9 years of average schooling nationwide and the 9.8 years of average schooling in the region studied here (INE, 2017). A low education level is a common feature in extensive meat sheep production systems worldwide (Toro-Mujica et al., 2020; Larrondo et al., 2018; Kılıç and Bozkurt, 2013; Thilakar, 2010). This is related mainly to the age of the farmers. The relationship between age and education level in the study population is illustrated in Table 3.

The average of the activities carried out by farmers was 3.3 (including sheep production) (Table 1). The activities in addition to sheep production that occurred more frequently were cattle production (86 %), vegetable cultivation (34 %), fowl and (or) pig breeding (31 %), handicrafts (23 %), extraction of wood or firewood (26 %), and tourism (17 %) (Table 2). These activities describe a particular reality in the study area that is different from northern areas in the country. No differences were observed in the number of activities between men and women. However, activities, such as vegetable and handicraft production, occurred more frequently in farms managed by women and cattle and sheep production by men (Table 2). To increase the profitability of the farms in the region, various projects have been developed to support the processing of wool and its use in the elaboration of handicrafts. These include the Wool Bank project (PYT-2016-0353) of the Foundation for Agrarian Innovation (FIA, 2016) and the BIP30422982-0 project "Strengthening of sheep farming through productive and commercial chains in the province of Palena financed by the innovation fund for competitiveness (FIC) of the Los Lagos Region" (FIC, 2015).

With regard to the dimensional variables, the average farm size was 134 ha, 39 % of surface dedicated to sheep production. This surface is similar to those reported by Milán et al. (2003) and Gaspar et al. (2008) in the typological groups identified in sheep systems of the Ripollesa

Table 1
Age and number of activities carried out on the farms according to the gender of the farmers.

Variable	Female	Male	Total	P value
Age (years)	58.3 $\pm$ 13.1	57.1 $\pm$ 15.5	57.5 $\pm$ 14.7	0.54
N° of agricultural activities	3.5 $\pm$ 1.1	3.2 $\pm$ 1.4	3.3 $\pm$ 1.3	0.1

Table 2
Qualitative characterization variables of the farmers and their farms (%).

Variable		Female	Male	Total	P-value
Gender (%)		35	65	100	–
Education	No studies	10	4	6	
	Incomplete primary	34	39	38	
	Complete primary	34	29	31	
	Incomplete secondary	11	10	10	0.44
	Complete secondary	8	12	10	
	Technical or University	2	6	5	
Age	< 30 years	3.3	4.5	4.0	
	30−39 years	3.3	11.6	8.7	
	40−49 years	18.0	17.0	17.3	0.27
	50−59 years	27.9	17.9	21.4	
	>60 years	47.5	49.1	48.6	
Agricultural activity	Bovine	77.0*	91.1*	86.1	
	Fowl/Pig	34.4	29.5	31.2	
	Vegetable	52.5*	24.1*	34.1	
	Goat	0.0*	8.9*	5.8	<0.01
	Firewood/wood	23.0	27.7	26.0	
	Handicrafts	44.3*	11.6*	23.1	
	Tourism	16.4	17.0	16.8	
Land ownership		91.8	80.2	84.3	0.05
Supplementation	Yes/No	86.9	81.3	83.2	0.34
	With hay	61.7	56.8	58.48	0.53
	With concentrate	81.9	72.1	75	0.14

* Cells with values that differ significantly from the expected average ($p < 0.05$).

breed and pasture sheep systems in Spain. These groups also share other characteristics with the farms studied, such as the orientation towards meat production, a pastoral feed base, and the family character. The average flock size was 66 sheep, of which 67 % were ewes. The sheep stocking rate was low, reaching 0.18 LU/ha, raising the sheep stocking rate in the area destined explicitly for sheep production to 0.79 LU/ha. This sheep stocking rate was similar to that observed in sheep systems in semi-arid and Mediterranean climates (Toro-Mujica et al., 2015; Gaspar et al., 2008). Although, the higher level of precipitation in the area would allow more production of pasture, and, as a result, a greater stocking rate, the soils of the studied here have suffered a process of erosion due to forest extraction. Therefore, the productivity of natural grasslands was limited (CIREN, 2010).

The most common sheep breeds were Corriedale (40 % of the farms), Suffolk Down (17 %), Romney Marsh (11 %), and Texel (11 %). There are farms that have up to 4 breeds, with the average number of breeds per farm being 1.5. All these breeds have a dual-purpose, allowing meat and wool production. The presence of the Romney Marsh and Texel breeds, and others with lower percentages, such as Dorset, Border and Golden sheep, are the result of different genetic improvement programs in the Region. Most of these programs were developed by the Institute of Agricultural Research and the Ministry of Agriculture. Thus, for example, the introduction of Dorset, Texel, Romney Marsh, and Suffolk Down rams of high genetic value was recently carried out under the "Patagonia Verde" Promotion Plan (INIA, 2019). The sale of lambs occurred in 100 % of the farms, and dirty wool was sold by 95 %. Both products were used on the farms, for lambs, through intra-farm consumption (in 95.4 % of the farms), and for wool, through the manufacture of handicrafts (in 23 % of the farms).

Ewes and rams were managed separately in 87 % of the farms. Breeding occurred during April or May. The resulting lambs reached their sales weight between October and the following March. December (62 %) and January (24 %) were the most significant months for sales associated with the increase in demand during the holidays and the beginning of the summer season in Chile. In 83.2 % of the farms, the sheep are commonly supplemented with hay and concentrates, in 59 and 75 %, respectively. Supplementation occurred in June to October, with August having the highest frequency of supplementation with hay (51 % of farms) and September with the highest frequency of supplementation with concentrates (62 % farms). The leading causes of elimination of sheep that stand out included age, lack of farm area, and diseases. Regarding the infrastructure and equipment that the farms possessed, 86 % had pens, 50 % had an irrigation system, 38 % had chutes, 32 % with a shed, 17 % with a baler, and 17 % with an electric fence.

Similar results were described in five regions of Brazil where the main problems faced by sheep farmers were related to technical issues, especially when it comes to the definition of adequate handling and reproduction techniques, as for breeding, lambing, selection, prophylaxis, health procedures, feeding and growth rate to enable high profitability (Campos, 2003).

3.2. Multivariate analysis

Through the processing and selection of the 341 columns of data resulting from the survey, a total of 120 variables were obtained. Of the 120 variables, 76 presented a coefficient of variation greater than 60 %. Therefore, they were retained (Frija et al., 2016; Toro-Mujica et al., 2012). With these variables, a correlation matrix was developed. By the correlation matrix, 28 variables were discarded for not presenting correlations greater than 0.5 and 27 for presenting correlations greater than 0.9 with any other variable. As a result, a total of 21 variables were selected to perform the multivariate analysis. Through principal component analysis, the five principal components (PC) that presented an eigenvalue greater than one were extracted (Gelasakis et al., 2017). Together, these five PCs explained 70 % of the variability in the data. The Kaiser-Meyer-Olkin (KMO) coefficient was 0.73 indicating the adequacy of the sample. Bartlett's sphericity test was significant ($p < 0.01$), indicating the adequacy of the analysis (Malhotra, 2004). Table 4 shows the five PCs, their relationship with the variables, and the percentage of the variance explained by each PC. PC1 was associated with the dimensional variables of stocks (ewes, rams, ewes culled, and lambs born), product sales (lambs sold and dirty wool sold), and intra-farm consumption (lambs consumed). The association of the first principal components with dimensional variables is a commonly observed characteristic in developing typologies in livestock production systems (Toro-Mujica et al., 2020, 2015; Ibidhi et al., 2018; Riveiro et al., 2013). PC2 and PC5 were related to animal feeding. Thus, PC2 was related to

Table 3
Education level of farmers in relation to age.

Education[1]	≤ 30 years	30−39 years	40−49 years	50−59 years	≥ 60 years	p-value	Total
No studies	0.0	0.0	0.0	0.0	13.1*		6.4
Incomplete primary	0.0*	13.3*	30.0	35.1*	48.8*		37.6
Complete primary	0.0*	26.7	30.0	40.5*	29.8		30.6
Incomplete secondary	42.9*	26.7	20.0	8.1*	2.4*	<0.01	10.4
Complete secondary	42.9*	20.0	13.3	16.2	2.4*		10.4
Technical or University	14.3*	13.3*	6.7	0.0*	3.6		4.6

* Cells with values that differ significantly from the expected average ($p < 0.05$).
[1] Data are presented as a percentage of farmers belonging to each class.

Table 4
Principal components (PC), eigenvalue, explained, and accumulated variance and correlation coefficients.

PC	Eigenvalue % explained variance (% cumulative variance)	Variables	Correlation with PC
1		Ewes (n°)	0.95
		Lambs (n°)	0.86
	5.7	Rams (n°)	0.84
	28.3	Dirty wool sold (kilos)	0.82
	(28.3)	Lambs sold (n°)	0.74
		Culled ewes (n°)	0.68
		Gimmer (n°)	0.65
		Lambs consumed intra-farm (n°)	0.53
2	3.5	Supplementation with hay (0: Without, 1: Adult sheep or lambs, 2: Adult sheep and lambs)	0.94
	17.3	Month of initiation of hay supplementation	0.88
	(45.5)	Supplementation with hay or concentrate (0: Without, 1: Hay or concentrate, 2: Hay and concentrate)	0.78
		Months with hay supplementation (n °)	0.78
3	2.0	Dead sheep (n°)	0.87
	10.0	Sheep mortality (%)	0.75
	(55.5)	Dead lambs (n°)	0.69
4	1.6	Sheep stocking rate (LU/ha)	0.83
	7.7	Farm area destined for sheep (% Farm area)	0.82
	(63.3)	Farm area (ha)	−0.66
5	1.3		
	6.7	Supplementation with concentrate (0: Without, 1: Adult sheep or lambs, 2: Adult sheep and lambs)	0.88
	(70.0)	Months with concentrate supplementation (n °)	0.81

aspects of flock supplementation, including the type of supplement, sheep category receiving the supplement, starting month and duration of the supplementation. PC3 represented the sheep mortality parameters, both in number and percentage. PC4 was associated with the farm intensification and specialization of sheep production. It was positively relating to the percentage of the farm area destined for sheep, the sheep farm stocking rate, and negatively to the total farm area. Finally, PC5 was associated with variables related to concentrate supplementation.

Fig. 2 shows the combinations of main components that allowed the clearest differentiation of the identified groups. Thus, the combination of PC1, PC2, and PC3 serves to differentiate groups III and IV from the rest of the groups; the combination PC1, PC2 and PC4, to differentiate groups II, III and IV; and PC1, PC2 and, PC5, to differentiate groups I, III and IV.

The cluster analysis that provided the best results was Ward's methodology with Euclidean distance. Using the elbow rule based on Ward's method (Ward, 1963), four groups of farms were identified (Fig. 2). The discriminant analysis correctly classified 97.1 % of the farms in the group obtained by the cluster analysis.

GROUP I. Mixed pastoral system with winter supplementation of concentrates. Group I (GI) corresponded, together with groups GIII and GIV, to one of the groups with the largest area (Table 5). As in the two groups mentioned above, in GI, less than 35 % of the surface was used for sheep production (Table 5). This GI was characterized by not using hay as a supplement (Table 6.). In replacing hay, the farms in this group incorporated concentrate, a practice observed in 100 % of the farms, starting during the winter months (97 % between June and October) and lasting around three months (Table 6). Flocks are small and no differences were observed in the technical variables in relation to the rest of the groups (Table 5).

GROUP II. Sheep pastoral system with winter supplementation. GII corresponded to the group with the most farm surface destined for sheep production, reaching an average of 80.5 % (Table 5). This is justified by the smaller farm surface. Despite the smaller surface size, these farms own the largest flocks. This characteristic was indicative of a specialization in sheep production, which was related to the lower presence of other activities (Table 6). Theirs larger flock size enabled the highest volumes of product sales (lambs and wool) and highest intra-farm consumption of lambs. The supplementation with forage and concentrates had average durations of 3.6 and 2.8 months (Table 5), respectively; however, it presents a wide distribution, finding farms with supplementation from January to October. The specialization in sheep production of this group was also reflected in the higher percentage of farms that sold slaughter.

GROUP III. Mixed pastoral system with winter supplementation. GIII corresponded to the group with the smallest surface devoted to sheep production (Table 5). The size of the flock and the sheep stocking rate was similar to groups I and III. All farms carried out supplementation with hay and concentrate. However, the concentrate supplementation started regularly later than in the other groups (mid-winter) (Tables 5 and 6). Given the scarce surface available for sheep production, supplementation with hay was required in the summer and winter months, explaining the greater amount of hay used ($p < 0.01$) (Table 5). The greater presence of purebreds declared is another variable possibly associated with the demand for supplementary feeding (Table 6).

GROUP IV. Mixed pastoral system with strategic supplementation. The GIV shared dimensional characteristics of the farm surface and surface destined for sheep and flock size similar to Groups I and III. However, it differed from these groups in the highest sheep surface

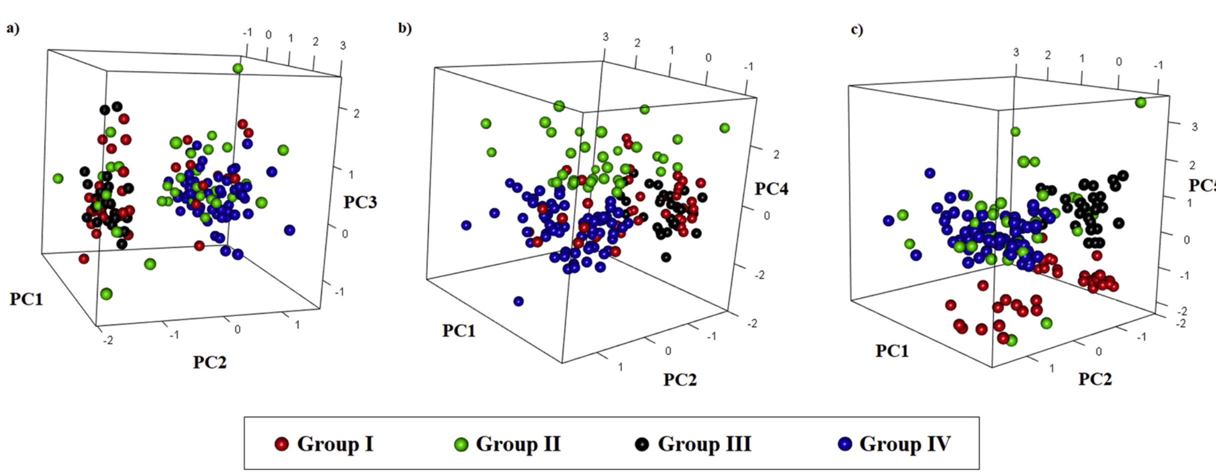

Fig. 2. Principal components involve in the separation of groups.

Table 5
Quantitative characterization variables of the sample and typological groups.

Dimensional variables	Group I	Group II	Group III	Group IV	P-value	Total
Total surface (ha)	152.6 ± 115.9^{a}	65.6 ± 104.6^{b}	146.2 ± 194^{a}	170.4 ± 186.6^{a}	0.02	133.9 ± 165.4
Sheep surface (ha)	26.1 ± 30.6^{ab}	29.5 ± 28.6^{ab}	18.4 ± 22.8^{a}	44.2 ± 82.2^{b}	0.05	28.1 ± 45.9
Flock size (LU)	7.9 ± 4.5^{a}	14.1 ± 15.5^{b}	8.9 ± 6.3^{a}	8.7 ± 4.7^{a}	0.01	9.9 ± 8.9
Ewes (n°)	34.6 ± 22.3	60.6 ± 71.8	41.4 ± 30.3	37.9 ± 23.9	0.03	43.7 ± 42.1
Ram (n°)	1.9 ± 1.1^{a}	2.7 ± 2^{b}	2.1 ± 1.2^{a}	2.2 ± 1^{ab}	0.06	2.1 ± 1.8
Gimmer (n°)	12.2 ± 10.7^{a}	22.4 ± 36.6^{b}	10.9 ± 8.5^{a}	12.7 ± 14.7^{a}	0.04	14.1 ± 20.3
Lambs consumed intra-farm (n°)	12 ± 7.5^{a}	17.5 ± 10.5^{b}	10.4 ± 7.4^{a}	14 ± 12.2^{ab}	<0.01	13.1 ± 9.7
Lambs sold (n°)	7.3 ± 8.4^{a}	16.7 ± 19.8^{b}	10.2 ± 11^{a}	8.7 ± 9.7^{a}	0.01	10.8 ± 13.3
Culled ewes (n°)	4.4 ± 4.1	7 ± 9.7	5 ± 6.3	6.3 ± 6.1	0.34	5.6 ± 6.9
Dead sheep (n°)	1.5 ± 3.2^{a}	9.4 ± 23.8^{b}	1.7 ± 3.2^{a}	5.8 ± 85^{ab}	0.1	4.3 ± 12.3
Dead lamb (n°)	7.4 ± 13.6	10.8 ± 20.8	5.5 ± 5.2	9.4 ± 9.7	0.19	7.8 ± 12.5
Dirty wool sold (kilos)	111.1 ± 105.5^{a}	243.5 ± 283.4^{b}	140.9 ± 132.6^{a}	127.5 ± 126.6^{a}	<0.01	154.0 ± 176.3
Forage consumed (N° of pack)	0 ± 0^{a}	48.8 ± 94.6^{ab}	84.5 ± 164.3^{b}	14.7 ± 41.5^{a}	<0.01	39.6 ± 106.9
Technical/productive variables						
Sheep stocking rate on surface destined for sheep (LU/ha)	0.81 ± 0.87	0.71 ± 0.82	0.98 ± 1.2	0.57 ± 0.53	0.18	0.79 ± 0.94
Surface destined for sheep (% Total surface)	21.5 ± 22^{a}	80.5 ± 31.4^{b}	24.3 ± 26.5^{a}	34.1 ± 32.1^{a}	<0.01	39.3 ± 36.6
Lambs consumed intra-farm (% Total lambs)	25.7 ± 15.7	26.8 ± 21.3	20.4 ± 13.5	23 ± 12.8	0.20	23.4 ± 15.8
Lambs sold in the month of highest sale (% Total lambs)	16.3 ± 17	27.9 ± 19.1	22.3 ± 16.3	19.7 ± 18.4	0.05	21.8 ± 17.8
Culled ewes (% Total ewes)	14.6 ± 15.9	14.2 ± 15.7	13.8 ± 13.6	18.9 ± 19.3	0.43	15.1 ± 15.8
Lambs (N° per 100 mated ewes)	72 ± 54.4	79.4 ± 89.9	70 ± 27.7	67.8 ± 38.6	0.79	72.0 ± 54.2
Sheep mortality (%)	5.6 ± 14.3	8.9 ± 17.2	4.6 ± 8.7	10.9 ± 14.0	0.11	7.1 ± 14.0
Lamb mortality (%)	14.9 ± 11.1	17.8 ± 20.7	17.7 ± 23.9	33.8 ± 66.4	0.12	20.9 ± 36.8
Twin sheep (N° per 100 lambing ewes)	7 ± 5.6	6.5 ± 6.7	9.7 ± 14.2	9.2 ± 11.5	0.46	8.4 ± 10.9
Months with hay supplementation (n °)	0 ± 0^{a}	2.8 ± 2.9^{c}	3.1 ± 1.3^{c}	1.3 ± 2.2^{b}	<0.01	2.1 ± 2.2
Month of initiation of hay supplementation (1−12)	0 ± 0^{a}	3.6 ± 3.6^{b}	7 ± 1.9^{c}	2 ± 3.3^{b}	<0.01	3.8 ± 3.7
Months with concentrate supplementation (n °)	2.9 ± 1.7^{b}	3.6 ± 3.2^{b}	3 ± 1.3^{b}	0 ± 0.2^{a}	<0.01	2.5 ± 2.3
Month of initiation of concentrate supplementation (1−12)	7.8 ± 1.5^{c}	6.1 ± 3.2^{b}	7.5 ± 1.2^{c}	0.2 ± 1.4^{a}	<0.01	5.6 ± 3.6
Breeds (n °)	1.4 ± 0.5	1.7 ± 0.6	1.5 ± 0.8	1.6 ± 0.9	<0.01	1.5 ± 0.7

^{a,b,c}Within row, averages with different superscript differ significantly (p<0.05).

(Table 5). This characteristic means that this group had a low percentage of farms with supplementation of both hay and concentrate. Thus, only 35.9 % of farms carried out supplementation, using only the 2.6 % concentrated supplement (Table 6). The supplementation was done for a short period, associated with strategic supplementation (the flushing or the first third of lactation) (Table 5). In this group, only 51.3 % of the farmers stated that they had purebred animals, mostly Corriedale (40 %) or Suffolk (36 %). The rest of the purebred sheep corresponded to animals of the Romney Marsh, Dohne, and Dorset breeds. This was due mainly to the introduction of purebred rams through government programs (INIA, 2019).

The results were in agreement with previous studies by Falcão et al. (2006) and Raineri et al. (2015) who describes low lamb production where the main obstacles observed by them were: (i) deficient feeding systems, especially in critical periods; (ii) low genetic quality of flocks; (iii) health issues, and (iv) deficient reproductive handling.

Despite having significant differences in the variables studied, the typological groups identified shared characteristics in terms of flock size and sheep stocking rates on the farm area dedicated to sheep production. In this regard, the same flock size is found in different production systems. This was possible given the extensive nature of the four systems identified (Morris, 2017). On the other hand, the flock size present in 84 % of the farms was less than 100 sheep. This flock size was the consequence of three phenomena associated with the geographic isolation that characterizes the area studied. The consequences of isolation included: in the first place, the difficulty of obtaining external labor to handle a greater number of sheep. Secondly, was the limited possibility of marketing lambs and, thirdly, the scarce supply of supplementary feed. In this last point, the results obtained in the variables associated with supplementation, such as type, month of initiation, and duration of supplementation, were associated with the availability of pastoral resources and harvest by-products. Thus, the GII, with the highest percentage of the farm area dedicated to sheep production and the fewer sources of stubble or crop by-products, and GIII with the smallest sheep surface, made comparatively greater use of preserved forage and concentrate. Technical indicators, such as fertility, mortality, and percentage of twin ewes, did not show significant differences between groups (Table 5). These indicators illustrated the weaknesses of sheep production in the area studied. As indicated by the INDAP (2007), sheep production in this area is carried out without greater specialization and under conditions of low technological level and precarious infrastructure and equipment. This context is consistent with the observations of Falcão et al. (2006). These authors state that as a consequence of the technical difficulties and the supply chain disorganization, lamb slaughter is late. This compromises carcass quality and limits access to the main market channels, slaughterhouses and supermarkets. Therefore, lamb offer becomes precarious and irregular around the year (Raineri et al., 2015). Similar scenario was described in Brazil where the productive chain is disorganized leading to the shortage of supply to the domestic market, unstable markets, along with a lack of scale and product standards (Braga Lobo, 2019). As shown in Table 6, no difference occurred in infrastructure or equipment between groups (p > 0.05). In relationship to the use of the shed, most of the farmers used it for sheep and feed storage (Table 6). The percentage of farms that used the shed for animals was higher in group III (p = 0.02), which was related to

Table 6
Qualitative variables for characterization of groups.

Groups		Group I	Group II	Group III	Group IV	Average	P value
Supplementation	With hay	0*	64.1	100*	32.4*	58.5	<0.01
	With concentrate	100*	84.61	100*	2.56*	83.2	<0.01
	With hay or concentrate	100*	92.3	100*	35.9*	83.4	<0.01
Community	Palena	54.8	44.7	42.9	30.8	42.7	0.24
	Futaleufú	45.2	55.3	57.1	69.2	57.3	
Gender	Female	28.1	41.0	39.7	28.2	35.3	0.44
	Male	71.9	58.9	60.3	71.8	64.7	
Presence of purebred sheep		59.4	69.2	79.2*	51.3*	65.9	0.05
Education	No education	6.3	10.3	3.2	7.7	6.4	0.41
	Primary incomplete	31.3	35.9	34.9	48.7	37.6	
	Primary complete	31.3	35.9	31.8	23.1	30.6	
	Secondary incomplete	18.8	5.1	12.7	5.1	10.4	
	Secondary complete	12.5	10.3	12.7	5.1	10.4	
	Technical or university	0	2.56	4.76	10.26	4.6	
Lambs consumed intra-farm		100	97.4	93.7	92.3	95.4	0.36
Sale of slaughtered lambs		28.1	53.9*	52.4	25.6*	42.2	0.01
Sale of wool		78.1	82.1	88.9	76.9	82.7	0.38
Handles ewes and rams separated		78.1	82.1	88.9	76.9	87.9	0.46
Lamb sale month	November	9.4	2.6	6.4	2.6	5.2	0.19
	December	34.4	53.9	60.3	47.4	51.2	
	January	34.4	20.5	12.7	18.4	19.8	
	February	3.1	10.3	3.2	2.6	4.6	
	March	0.0	2.6	0.0	0.0	0.6	
Activities	Bovines	90.6	79.5	90.5	82.1	86.1	0.32
	Fowl/Pigs	50.0*	28.2	33.3	15.4*	31.2	0.02
	Vegetable	34.4	35.9	38.1	25.6	34.1	0.62
	Firewood/wood	18.8	17.9	33.3	28.2	26	0.26
	Handicrafts	21.9	17.9	22.2	30.8	23.1	0.58
	Tourism	18.8	15.4	14.3	20.5	16.8	0.85
	Goat	9.4	2.6	4.8	7.7	5.8	0.59
Infrastructure and equipment	Electric fence	9.4	10.3	22.2	23.1	17.3	0.19
	Pens	78.1	89.7	85.7	89.7	86.1	0.46
	Baler	6.3	20.5	23.8	10.3	16.8	0.09
	Chute	28.1	282	46	43.6	38.2	0.16
	Shed	93.8	89.7	98.4	97.4	95.4	0.19
Use of shed	Sheep	75	74.4	90.5*	66.7*	78.6	0.02
	Feed	75	71.8	92.1	87.2	83.2	0.07
	Machinery	12.5*	33.3	46.0*	23.1	31.8	0.005

[1] Within column data are presented as a percentage belonging to each class.
[*] Cells with values that differ significantly from the expected average ($p < 0.05$).

the higher sheep stocking rate of this group and the greater presence of purebred (Tables 5 and 6).

The typological group of each farm was independent of the community (X^2, 4.2 gl3 p = 0.24), owner's gender (X^2 2.67, gl3 p = 0.44), and owner's education (X^2, 15.49 gl15 p = 0.41).

In all the groups identified, other activities were performed, in the forestry and livestock sectors and outside it, such as tourism and handicrafts. Forestry, agricultural, and livestock activities, such as bovine production, vegetable cultivation, firewood or wood production, and goat production, did not show differences between groups. A lower presence of fowl or pig production was observed in the GIV, probably associated with the business nature of some of the larger farms. The pluriactivity, defining as the combination of agricultural and non-agricultural activities in family-owned farms for the generation of economic income (Loughrey et al., 2013), has been identified as an effective way out of poverty in non-poor and poor smallholders in the Mexican ejido (Janvry and Sadoulet, 2000). In the study area, the pluriactivity currently is being based on self-employment in complementary activities with agricultural production, such as tourism and handicrafts. Thus, the management of family farms, such as small enterprises, emerges as an alternative to the extent that tourism increase the demand for lambs and handicrafts (INDAP, 2007), making it possible to incorporate these activities within the farm. As indicated by Pacheco et al. (2012), the satisfaction of this need requires a socio-productive chain, in which farmers act as a "human with resources". These "human with resources" needs to become the focus of the comparative advantages of the farm-enterprise when using their competences (abilities, skills, knowledge, and knowledge management) both to fulfill professional and personal objectives, as well as for obtaining profitability in the farm-enterprise.

The presence of several silvo-agricultural and livestock activities (Table 6) is justified by the need to take advantage of the whole land area with limited availability of labor, in the use of the forest resource (either by silvopastoralism or through the extraction of firewood or wood) and the need to produce fresh food (vegetables and meat) given the geographic isolation. Additionally, the presence of more than one species of livestock in more than 80 % of the farms and their integration with agroforestry is another way to diversify farming systems that have been proposed as a mechanism to address the many sustainability issues of today's agriculture (Martin et al., 2020).

Regarding the infrastructure and equipment that the farms have, 86 % had pens, 50 % had an irrigation system, 38 % with chutes, 32 % with a shed, 17 % with a baler, and 17 % with an electric fence. No significant differences emerged between groups.

The general scenario of sheep production systems in Chile is similar to that described by Raineri et al. (2015) in Brazil, who concluded that sheep production needs technical and economic improvement to affront commercial lamb production. Farmers need to upgrade basic handling procedures, data recording, animal feeding, employees and machines efficiency and technology adoption. These issues demonstrate the importance of providing tools and orientations where rural extension and technology diffusion must be improved a key factor.

4. Conclusions

Sheep production in extreme areas is developed within family farms as part of an integrated system of activities that naturally uses circular economy strategies (such as using crop residues in animal feed or the use of pruning or thinning remains to obtain firewood) and sustainable practices (such a pluriactivity and multi-species livestock). The existence of this system allows family members to obtain products both for intra-farm food and for the manufacture of textiles and handicrafts increasing food security. Due to the absence of formal marketing channels resulting from geographic isolation, the surpluses produced are sold locally. This phenomenon would be a common pattern in small farmers in South America. This absence of marketing channels, added to the scarce availability of labor, influences the size of the flock manageable by the family members. Despite identifying four typological groups, only group II presented a slightly larger flock size; this is consistent with the greater specialization in sheep activity. Other differences between the groups identified were related to the total farm area, the importance of sheep production on the farm, and the quantity of supplementary feed for sheep. With regard to technical indicators, high mortality, low fertility, and prolificacy rates were observed in this study. Although government institutions have introduced breeds with a high genetic potential to increase these indicators, integral programs should be based on local culture and also must consider the higher nutritional requirements of these biotypes, as well as the need for infrastructure (given that these animals are not adapted to local handling, climatic, and sanitary conditions), are required.

Given the government strategies to support the study area and the strong tourist component of governmental assistance, the sheep farmers need to modify their management strategies. These strategies will depend on territorial opportunities and limitations, where some systems would remain as subsistence economy and other would be that the farmers to become farm-enterprises. This would mean that within the socio-productive chain, the family members would act as a "human with resources" and through complementary to sheep production activities, increasing the profitability of their farm-enterprise while developing and reaching new personal goals.

Declaration of Competing Interest

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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