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Sheep Farming

Herds Husbandry, Management System, Reproduction and Improvement of Animal Health

Edited by Manuel Gonzalez Ronquillo and Carlos Palacios Riocerezo

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Meet the editors

Dr. Manuel González Ronquillo obtained his doctorate degree from the University of Zaragoza, Spain, in 2001. He is a research professor at the Faculty of Veterinary Medicine and Animal Husbandry, Autonomous University of the State of Mexico. He is also a level-2 researcher. He received a Fulbright-Garcia Robles fellowship for a postdoctoral stay at the US Dairy Forage Research Center, Madison, Wisconsin, USA in 2008–2009. He received grants from Alianza del Pacifico for a stay at the University of Magallanes, Chile, in 2014, and from Consejo Nacional de Ciencia y Tecnología (CONACyT) to work in the Food and Agriculture Organization's Animal Production and Health Division (AGA), Rome, Italy, in 2014–2015. He has collaborated with researchers from different countries and published ninety-eight journal articles. He teaches various degree courses in zootechnics, sheep production, and agricultural sciences and natural resources. Dr. Ronquillo's research focuses on the evaluation of sustainable animal diets (StAnD), using native resources of the region, decreasing carbon footprint, and applying meta-analysis and mathematical models for a better understanding of animal production.

Dr. Carlos Palacios Riocerezo obtained a veterinary degree from Veterinarian by the University of León, Spain, in 1991. Since then, he has worked as a veterinarian and veterinary technician specializing in dairy sheep breeding, reproduction, artificial insemination, animal nutrition services, and sheep farm management. Dr. Palacios obtained his Ph.D. in Sheep Health and Management from the University of León in 2010. He is a Full Professor of Animal Production at the Faculty of Agricultural and Environmental Sciences, University of Salamanca, Spain, where he teaches degree courses in Agricultural Engineering.

Contents

Preface

Sheep were domesticated by humans many years ago and throughout their history have been used to supply meat, milk, wool, and skin to different populations worldwide depending on geographical location, breed type, and dietary needs. This book provides insight into how sheep production is currently approached around the world.

Dr. Manuel González Ronquillo and Dr. Carlos Palacios Riocerezo have extensive experience in research and the development of scientific knowledge for farmers in two very different areas of the world. Jointly, they have produced a work that brings together very different geographical situations, management practices, and production systems, from the herds in the southernmost part of South America to the region of Magallanes, describing the herds' husbandry and management systems. This book describes sheep husbandry and management throughout the year, the nomadic and semi-nomadic shepherds of southern Poland, indigenous and minority breeds such as the Odisha in India, difficulties of applying reproductive technology in the northern Maghreb in Africa, the social and environmental structure of the dairy flocks of Castilla and León in Spain, and analyzes wool production in sheep in Mexico and North America. The book reviews the current situation of diverse sheep production worldwide and considers its future in a totally globalized world, with serious environmental problems and in which the rural world, linked to sheep farming, is experiencing one of its greatest crises. One chapter analyzes the role of cryptosporidiosis in sheep welfare and economic loss and provides information on how to minimize and deal with the infection. This book appears at a key moment in the relationship between sheep and humans, providing keys to provide sustainability, adapting to modern knowledge, and gathering ancestral, sustainable, and opportune practices to provide hope for livestock farmers in the poorest areas of the planet.

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Section 1

Herds' Husbandry and Management System

Chapter 1

Magallanes Sheep Farming

Sergio Radic-Schilling, Francisco Sales, Raúl Lira, René Muñoz-Arriagada, Paulo Corti, Nilo Covacevich, Jorge Ivelic-Sáez, Iván Ordoñez, Osvaldo Vidal, Ricardo Echeverría and Camila Sandoval

Abstract

The Magallanes region in Chilean Patagonia encompasses 13 million hectares with approximately 3.6 million used for agricultural and livestock systems. This portion is located to the east of the Andean Mountain chain in the rain shadow zone, with annual precipitation increasing along an east to west gradient from 200 to almost 1,000 mm. To fully describe sheep farming in the Magallanes region, many topics need to be addressed, including sheep production and management, existing vegetative communities, livestock-wildlife interactions, and economic diversification into agritourism and another sheep industry products. All these give shape to the story of the development of sheep farming in Magallanes, which is important at the regional and national level. Three key points are identified that together can lead to a successful future for the industry: sustainable management, human resources and the market.

Keywords: Chilean Patagonia, sheep production, grazing systems, fodder crops, artificial insemination, breeding, meet quality, wool production, sheep cheese, wildlife, animal welfare, agritourism

1. Introduction

The first sheep were brought to the Magallanes region from Chiloe in 1845 as a food source for the region's new human settlements. The Magallanes governor encouraged the development of a larger sheep industry, which began in January 1877 with the arrival of the first Cheviot sheep from the Falkland Islands (Malvinas). Progress in Magallanes throughout the last 145 years has transformed the region into the most important sheep farming area of Chile via the development of both, meat and wool production. In the last 20 years, improvements have been realized through a strategic use of management techniques (strategic feeding, grazing, soil fertility, water supply, crossbreeding and brush control) and new technologies (plow machinery, direct drilling, artificial insemination, embryo transfer, dietary supplement formulation, satellite imagery, silage baling, and electric fence) that have enhanced both, process efficiency and product quality, forward to sustainability management.

To understand the different aspects of sheep farming and its development within the socioeconomic and environmental context of the Magallanes region, this chapter covers topics including location, climatic conditions and main characteristics of the livestock use area, common grazing management systems, locally-adapted fodder crops, artificial insemination, the main breeds (Corriedale, Merino mainly and meat crossbreed), breeding, lamb meat quality under different grazing regimes, wool management, lactation curve and cheese production, animal welfare, sheep-wildlife interactions, and rural tourism.

2. Geographical area and weather

The Magallanes region corresponds to an extensive territory located in the extreme south of Chile and the South American continent, encompassing the meridional section of Patagonia and the occidental part of the Isla Grande de Tierra del Fuego, and the numerous archipelagos that make up a strip adjacent to both parts, ending in the south with the Cape Horn archipelago. The region extends from 48° 40′ to 56° 30′ south latitude (the greatest latitudinal amplitude in Chile), covering an area of 132,033.5 km^2 (**Figure 1A**) [1]. The region is characterized by a marked physical contrast, generating different geological, orographic and climatic zones, which determine high amplitude in terms of vegetation types [3]. Likewise, there is a pronounced gradient of precipitation from west to east, going from more than 5.000 to less than 200 mm per year respectively [4, 5]. These characteristics make it evident that, in Magallanes, the territory of the eastern section is the most suitable for human life, and that is where the cattle activity has been established since 1870 [1, 6].

The livestock use area is located mainly in the eastern section of the Magallanes region, extending between 50° 36′ and 55° 19′ south latitude and 67° 2 ‘and 73° 47’ west longitude, covering a surface area of 35,962.6 km^2 distributed mainly in the provinces of Magallanes, Tierra del Fuego and Ultima Esperanza (15,577.9, 13,502.2 and 6,559.9 km^2 respectively). With less representativeness and in the southernmost distribution lies the livestock territory of the Chilean Antarctic province with 322.5 km^2

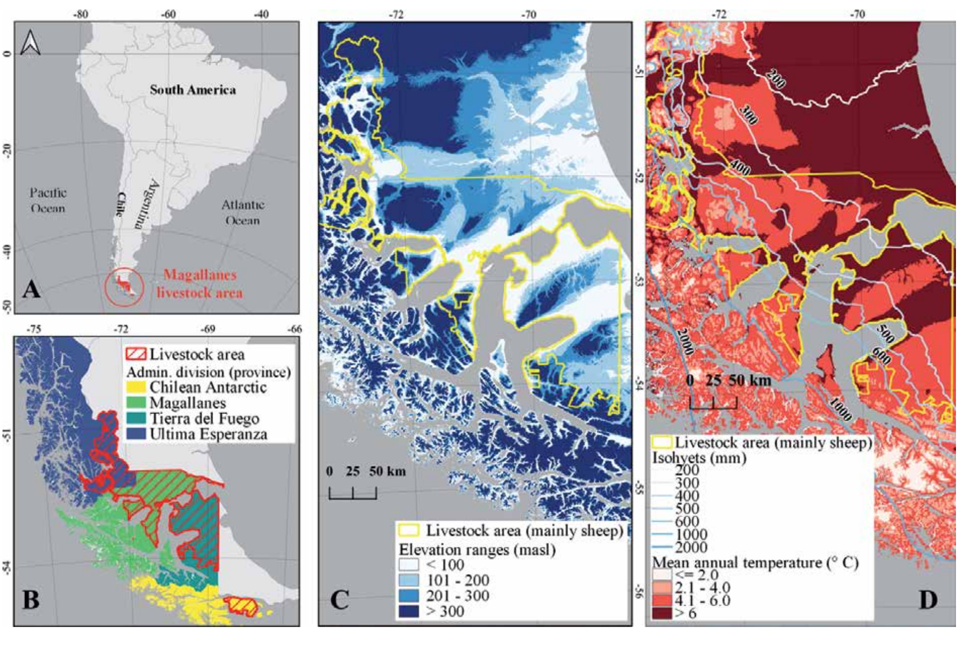

Figure 1.
Cartographies of the area of livestock use in the Magellan region. A: General location. B: Livestock use according to administrative division. C: Elevation ranges. Source: Own elaboration from ASTER GDEM digital elevation model. D: isohyets (mm·year^{-1}) and isotherms (annual mean ° C) (prepared by author based in Ref. [2]).

(**Figure 1B**) [7]. The livestock use area can be divided into three provinces from north to south (the area corresponding to the Chilean Antarctic province is not considered in this analysis). The first section located in the Ultima Esperanza province presents spatial and topographic patterns different from the other sections (Magallanes and Tierra del Fuego), corresponding mainly to a transition strip between mountain ranges and the eastern plains, characterized by plateau sectors crossed by mountain chains with heights that rarely exceed 1000 masl (**Figure 1B**). The Magallanes and Tierra del Fuego sections present similar characteristics, beginning with a western sub-Andean transition strip that gives way to extensive eastern plains, corresponding to mainly flat territories, with low elevations and moderate undulations (**Figure 1C**) [3].

According to [8], from a climatic point of view, based on Koppen classification, this area can be defined as a trans-Andean climate with steppe degeneration in its western fringe and a cold steppe climate in the eastern plains sector. In the former, we can find annual average temperatures ranging from 2.6 to 6.6° C, while in the cold steppe climate the annual average temperatures can range between 4 and 7.4°C (**Figure 1D**) [2, 8]. On the other hand, the area of interest is located in the sotavento zone (east) of the Andean Patagonian mountain range, which despite presenting spatial discontinuities in its southern distribution, is the main geographical feature of the region and forms an orographic barrier that generates local climatic changes [5, 9]. This is how rainfall in the livestock use area can drop from approximately 600 mm to less than 200 mm per year in the direction of the Atlantic coast in the sections of Magallanes and Tierra del Fuego, while in Ultima Esperanza the rainfall ranges from 1,000 mm to 300 mm in the same direction W-E (**Figure 1D**) [2].

The marked variation in rainfall in the area of livestock use is reflected in the present vegetation, which could be categorized into three ecoregions: the Patagonian steppe, the deciduous Magellan forest and evergreen forest, but the latter have a small participation. The dominates the sub-Andean region, is present in the three provinces of the area of livestock use, characterized by associations of *Nothofagus pumilio* (lenga) and also including forests of *Nothofagus antarctica* (ñirre) and associations with *Nothofagus betuloides* (coihue de Magallanes) in the most humid sectors [3]. It is worth mentioning that in this ecoregion and specifically in the area of livestock use, there are extensive areas of forests that were formerly burned with the purpose of enabling land for livestock [10] and that today are known as naturalized grasslands. Dominating the area of the eastern plains, we find the Patagonian steppe, defined as a hard grass community without the presence of trees [8]. The characteristic specie of this ecoregion in Magallanes is the tussock *coiron* (*Festuca gracillima*), which may be present to different degrees of dominance or even absent in some cases. In this ecoregion, three large types of communities can be distinguished: a) natural grasslands, made up of coiron grasslands, vegas (mesic grasslands) and saline grasslands, b) scrublands, represented mainly by *Chilliotrichium diffusum* (romerillo) and other species less distributed and c) heaths (sub-shrubs), where *Empetrum rubrum* (murtilla) stands out [11]. It is important to highlight that 91.8% (24,434.2 km^2) of the Patagonian steppe area present in Chile is located in the livestock use area of the Magallanes region and the Chilean Antarctic [11].

3. Grazing systems in Patagonian grasslands

The soils in the grazing fields in the region de Magallanes in Southern Chile are glacial and fluvio-glacial, with sandy-loam and loam-clay-sandy textures and a shallow surface soil horizon with mid to high organic matter content. The soils classification is dominated mainly for mollisols, but also histosols, inceptisols, espodosols and aridisols. Mineralization is very slow, implying severe nitrogen deficiency, also phosphorus and sulfur are limiting factors; pH values range from west to east from less than 4.8 rising to 7.7 where topography favors humidity and the accumulation of salts [11]. The photoperiod in summer is 12–14 hours/day, favorable for most long-day grasses. Dominant vegetation includes 32.7% of native shrubs and tussock grasses (*Chiliotrichium diffusum – Festuca gracillima*); 26.9% of tussock and naturalized grasslands (*Festuca spp, Poa spp)*; 12.2% of dense shrubs (*Ch. diffusum-Empetrum rubrum*) and 16.5% forests (*Nothofagus pumilio*). Sown and improved pastures (*T. repens; D. glomerata; Festuca spp)* comprise 2.5% of the total area, and about 5% is scattered highly productive humid areas or wetlands (also called vegas) of glacial and morrenic origin (graminoids). The mean nutritive value of native grasslands is low (roughly less than 9% protein and 8.75 MJ EM/kg DM) but selectivity and seasonal variations allow an extensive grazing system sustaining at present over 1,570,000 sheep [12] and 100,000 cattle [7].

3.1 Patagonian grazing systems

Sub-Antarctic rangelands were originally dominated by dense high tussocks (*Festuca sp.)* and less palatable shrubs. However, after the onset of the sheep industry, stock numbers rose to about 3 million by mid-20th century [13] and the grazing vegetation community shifted, first towards short tussocks and an inter-tussock cover of dense, low stature grasses and geofites, and later towards growing patches of invaders such as *Taraxacum sp., Agrostis sp., Aira sp.* or *Hieracium sp.* and even bare soil following the humidity gradient. In contrast, wetlands are dominated by more palatable species [14, 15] with higher growth rates in comparison to the sites dominated by *F. gracillima* [16].

The extensive grazing management in Patagonia (Magallanes region in Chile and Southern Patagonia in Argentina) is defined as a seasonal continuous grazing system, with summer set-stocking on paddocks above 150 m of altitude. Early on, grazing was adapted for wool production, a productive system with lower nutritional demand. The productive system has since shifted towards meat production, increasing the nutritional requirements of sheep due to the pregnant ewe and lamb raising [17]. Considering an estimation of dry matter consumption by an ewe of 50 kg live weight raising one lamb is around 650 kg DM year^{-1}.

The Sub-Antarctic rangelands (also called coironales) have an herbage mass production between 33 and 1439 kg DM ha^{-1} year^{-1} (depending on edaphoclimatic condition and grazing management) and are dominated by *F. gracillima* [16], a low palatability tussock species with low nutritional value that does not fulfill the minimum requirements of energy and protein for sheep maintenance and growth [18]. By comparison, wetlands or valley greens in Magallanes represent just 5% of the total productive surface with herbage mass production that ranges from 500 kg DM to 11,000 kg DM ha year^{-1} [16, 19]. These differences are due to the wetland's intrinsic properties [14, 20] and poor farm organization to do not separately fence wetlands from the less productive sites (rangelands dominated by *F. gracillima*), leading to overgrazing due to continuous use, and increasing the heterogeneity within and between paddocks due to selective grazing [21], increasing the risks of soil erosion and ecosystem degradation for both rangelands and wetlands. Therefore, due to their difference in growth potential, rangelands dominated by *F. gracillima* need to be managed from an extensive management approach whereas wetlands are more adapted to an intensive use [17].

3.1.1 Continuous grazing system

Extensive pasture size and large herd numbers (thousands of animals), combined with the climatic conditions and cultural traditions, have led to seasonal continuous grazing being the most common livestock production management approach. This extensive management system is characterized by large paddocks of hundreds of hectares, designed to separate stock categories rather than to target defoliation periods. The defoliation period is determined by season, sheep physiological periods and location of the grazing sites. In sub-Antarctic rangeland, snow cover determines when and where herds graze. The grazing year is split in two periods, with summer grazing from December to May in wetlands or sites with altitudes of 150 m above sea level or greater. Winter grazing occurs from May to December in lower altitude sites with a more favorable temperature range during the coldest months [17, 22]. Winter grazing generally overlaps with lactation and postpartum periods [22, 23].

Even though the disadvantages of continuous grazing in highly productive livestock systems are clear, in low-producing rangelands, the disadvantages are more ambiguous. It has been indicated in medium and long-term experiments [24] continuous grazing with the correct stocking rate, calculated based on herbage mass production, is an effective way to control desertification and achieve good animal performance [24, 25]. However, it is recognized that continuous grazing can increase heterogeneity [25] and weed invasion [26] on overgrazed sites.

Sheep actively select preferred species based on plant phenology (tender shoots and new regrowth, flowers and fruits) thus, in continuous grazing management, sheep overgraze the more palatable material, under grazing or leaving untouched older shoots. Recommended grazing practices imply an even, controlled defoliation height, followed by a specific regrowth period. The latter is supported by physiological plant research performed in several species [27–31], suggesting that, independent of the grazing system or ecosystem evaluated, vegetative species, particularly forage species, depend on energy reserves to regrow following defoliation [32] and to survive after drought periods [33]. Thus, selectivity must be avoided through careful estimation of grazing pressure. This requires more, smaller paddocks of similar vegetative communities, and strict control of grazing frequency. Animal nutrition must be considered, since enforcing the consumption of low nutritive value material may not be tolerated by younger or pregnant sheep. Modifying the traditional system is a major task implying qualitative and quantitative changes in both labor and mind set.

3.1.2 Rotational grazing

For rotational grazing to be performed, it is necessary to improve farm organization and increase the number of paddocks, separating different vegetative communities, such as wetlands, rangeland and forests, to avoid the negative effects of seasonal continuous grazing [21]. Several types of rotational grazing have been proposed for rangeland grazing management, however, as sheep reproductive phenology has to be considered [23], two of them could be applied in the Magallanes region: 1) rotational deferred grazing; 2) traditional rotational grazing with a high animal density [17, 24, 25].

Rotational deferred grazing: In this system, each paddock is rested for a full year at some point in a multi-year rotation to allow species recovery and reseeding [24] and to recover ecosystem resilience after years of defoliation [25]. There are no clear results in animal performance when rotational deferred grazing is compared to continuous grazing [24]. Furthermore, [25] indicated that in Moy Aike Chico, there were no important differences between a rotational deferred grazing system and continuous grazing in terms of animal production.

Traditional rotational grazing: There have been a few examples in the region with different frequencies and intensities. However, high intensity grazing is not recommended in rangeland settings due to the diminishment in animal performance and the low durability of the rangeland [24]. Grazing with low intensity and short duration at an experimental level (Experimental station Leleque, Southern Patagonia) showed an improvement in animal performance, however, the low growth rates during winter together with a low precipitation, mains factors that limit the herbage growth in Patagonia, meant the resting periods would not be long enough for forage species to recover [25]. There is not enough evidence of the benefits of rotational grazing over continuous grazing in ecosystems with low potential growth under a proper stocking rate [24, 25, 34]. However, rotational grazing showed benefits over continuous grazing in sites with high potential growth such as in sites with higher rainfall or wetlands.

In 2004 a rotational experiment with lambs was carried out on a wetland in Tierra del Fuego. The wetland was excluded from the rest of the paddock and regenerated by direct drilling (zero tillage) with a mix of species including *Lolium perenne*, *Festuca arundinacea*, *Dactylis glomerata*, *Trifolium repens* and *Plantago lanceolata* at a seeding rate of 28 kg ha^{-1} of grasses and 8 kg ha^{-1} of broadleaf species. Nitrogen, phosphorus, potassium and sulfur were applied at 46–46 – 22 – 22 kg ha^{-1}, respectively. The original botanical composition evaluation identified *Azorella trifurcata*, a creeping plant without livestock value, as the dominant species. The natural grassland reported an average gross protein value of 40 g kg^{-1} in. After four seasons, the trend of dry matter production was analyzed. In the first year, approximately 1035 kg DM ha^{-1} were produced, and the annual average for the next three years was no more than 3600 kg DM ha^{-1} while the natural grassland in the exclusion zone (5 hectares) produced up to 700 DM kg ha^{-1} annually during the four seasons. In the last season, lamb liveweight gain after one month of rotational grazing (stocking density of 80 lambs ha^{-1}) was 2.05 kg per lamb $moth^{-1}$, significantly higher than the gains in the traditional grazing system (1.39 kg per lamb and a stock density of 2 lambs ha^{-1}).

3.2 Future perspective

Modification of the traditional management is imperative to stop the depletion of the ecosystem functioning caused by sheep overgrazing in the Magallanes region. Ecosystem parameters such as vegetation, soil and water have to be considered to reach a sustainable productive system. Remote sensing technologies are an excellent tool for planning and evaluating changes in paddock grazing duration and timing, where University of Magallanes has developed this technology with use of satellite image in the agricultural area of the region from 2003. Also, the study of soil microbiology is an incipient area in development and could be an excellent assistance for soil fertility and grassland production. Efforts to shift the traditional paradigm from a sole focus on animal condition and performance to one that includes ecosystem functioning exist [35]. However, controlled experiments have to be performed to determine the necessary resting periods for the recovery of the rangeland and wetland vegetation, soil and water parameters.

4. Fodder crop

Livestock production in Magallanes depends on rangelands as the main source of food [36]. However, rangeland vegetation alone cannot meet sheep nutritional requirements, especially during peak nutritional demand (for example, the third trimester of pregnancy) [37]. Although wetland areas can provide food in quantity and quality, these are in a state of progressive degradation or are not capable of sustaining an acceptable production throughout the year due to erratic forage production. Since the beginning of sheep production in the region, farmers have seen the need to establish forage crops as a hay source, during critical physiological periods and harsh weather, or for grazing with the objective of increasing lamb weights before slaughter.

Establishment and development of sheep farming began in the Magallanes region during the second half of the 19th century. Large land concessions by the State and investment from private companies allowed the growth of the sector in the southernmost region of Chile [36]. Establishment of forage crops should be considered within its historical context.

In 1976, the Magallanes region had around 248,504.6 ha of sown grasslands, which could be divided between annual crops and permanent grasslands [38]. Ten years later, there were between 104,878 ha [39] and 194,185 ha [40], which were based on the use of forage mixtures such as cocksfoot (*Dactilys glomerata*), common velvetgrass (*Holcus lanatus*), white clover (*Trifolium repens*), monophytic grasslands of common velvetgrass, alfalfa (*Medicago sativa*), *Festuca rubra* and *Agropyron elongatum*. Although the Tierra del Fuego Livestock Society planted 10,000 ha year^{-1}, today the vast majority are missing or in a state of degradation [41].

Current numbers indicate that there are no more than 6,039.2 ha of forage crops, of which the vast majority is alfalfa. However, [42], estimates that there are currently around 9,800 ha of alfalfa in the region. This is because state subsidy programs that begun in 2004 have allowed ranchers to establish fodder crops. Sowing grasslands is a necessity on the part of the agricultural sector and the area devoted to forage crops has been increasing. Although there is a wide range of species and cultivars on the market, only a few are able to establish themselves and produce desired yields due to edaphoclimatic conditions.

Among the most adaptable species are oats (*Avena sativa*) as the main annual crop and alfalfa and mixed meadows (mixes of cocksfoot -*Dactylis glomerata*-, tall fescue -*Festuca arundinacea*- and white clover –*Trifolium repens*) as permanent meadows. There are two different establishment methods for perennial plantings in Magallanes: a) traditional tillage; b) zero tillage by direct drilling. This last method is unique, but its effectiveness depends on site conditions such as species competition, soil humidity and soil depth. Some examples of typical direct drilling in the region are alfalfa on tussock steppe (without use of herbicide) and mix of grasses with white clover on meadows.

Rainfall during the growing season strongly influences yields since regional production is based on dryland systems with no irrigation, but there is an incipient advanced irrigation technologies as center pivot in Tierra del Fuego. The current varieties of oats have yields that can range between 5,000 and 10,000 kg DM ha^{-1} [43, 44]. Other annual crops such as hybrid rye can produce between 8,000–12,000 kg DM ha^{-1} [45]. Cocksfoot can yield from 3,000 to 7,000 kg DM^{-1} in the third year from the establishment, while tall fescue can produce 4,000–6,000 kg DM ha^{-1}.

Without a doubt, alfalfa is the main forage crop in the Magallanes region. This species is preferred because of its ability to establish itself in the vast majority of the soils and climatic districts of Magallanes (**Figure 2**). Fall dormancy level 3–4 varieties capable of going into dormancy in the autumn-winter months are used. At least three years are required for the crop to enter full production, increasing forage production from 400 kg DM ha^{-1} [46] in the first year to a potential of 12,000 kg DM ha^{-1} [47].

Management of forage crops in Magallanes is based, normally, on cutting for hay or silage during December and January. In March and April, following regrowth, fields are grazed in order to increase the weight of lambs before slaughter.

Figure 2.
Fodder crop of Alfalfa in Torres del Paine, Magallanes region (Image by Jorge Ivelic-Sáez).

5. Artificial insemination

Farm productivity depends on each sheep producing at least one lamb each year. The use of natural service during the breeding period is the most common practice in commercial Magallanes farms. However, since the 1970s, artificial insemination (AI) has been part of the production system, especially in stud farms, in order to accelerate the genetic progress and the production of flock replacements (males and females).

5.1 Artificial insemination: a productive tool

AI has been used mainly in genetic and selection programs, in order to improve the commercial traits of interest [48]. For dual purpose breeds such as Corriedale, increasing fleece weight, reducing fiber diameter, and augmenting lamb weight at weaning are normally the traits to be improved via introduction of animals with a higher genetic value [49]. In Merino animals, fleece weight and reduced fiber diameters are the main selection traits. Among the different alternatives, intracervical AI using fresh semen is the most widely used AI technique.

5.1.1 Preparing the animals for artificial insemination with fresh semen

Selection of males is the first step in AI programs. Regardless of the origin (self-produced or acquired from a sheep stud farm), rams will be selected according to their phenotypic and productive characteristics. Genital tract soundness, evaluation for brucellosis (*Brucella ovis*), and conformation of legs, hoofs, and mouth, are normally checked by the farmer at least one month before the onset of the reproduction season. A good body condition and body weight will also be checked prior to the AI program as it influences the reproductive efficiency of animals [50], particularly prolificacy in Magallanes [51]. Similarly, females selected as recipients will be checked for body condition and any health issues, paying special attention to age, teeth, mouth and udder conformation and soundness.

5.1.2 Estrus synchronization protocols

Different estrus synchronization protocols are used in Magallanes selected based on factors such as labor, cost and efficiency. Although some producers may use the natural estrus, two options of synchronization are commonly utilized. The first one is the use of prostaglandin analogs in one or 2 doses, separated by 11–12 days [52]. The second one uses progestogens in the form of sponge pessaries or CIDR devised, used for 11 to 14 days available in the market with estrus concentration of 90% of the animal in 81 h after sponge withdrawal [53]. A protocol using equine chorionic gonadotrophin (eCG) hormone at the time of CIDR withdrawal is normally used to improve ovulation rate and fertility [54].

5.1.3 Artificial insemination facilities in Patagonia

Due to cold weather conditions, the use of indoor facilities is highly recommended. The basic infrastructure is a room for semen extraction, with a head stock for a female in heat, and a lower area for the personnel to have a better access to the ram penis. Lubricant gel, warmed water and artificial vagina for practicing, are the basics for obtaining semen. After semen collection, quality evaluation (e.g., volume, concentration, motility, etc.) and dilution takes place. This occurs in the lab area, where room temperature is maintained between 20 and 25°C. Access to the sheep in heat is through a window located at the height of the vulva, with the operator standing in an insemination pit in the floor of the lab and barn, and the ewes will be transported in a trolley with wheels on rails.

5.1.4 Fresh semen artificial insemination

Regardless of the synchronization protocol, the use of teaser rams helps in the identification of ewes in heat. Teaser rams are painted with a mix of edible oil and colored soil in a ratio of 2 liters of oil per 1 kg of soil. The use of a harness with a crayon has been previously evaluated, however; special attention must be paid to crayon selection, since temperatures below 0°C, which are normally observed during the winter, interfere with a good painting of ewes in heat. The mix with oil must follow a soil color gradient, starting with light colors and finishing with dark ones (e.g. yellow, red, blue and finally black) as this allows the identification of animals in different reproductive cycles, which normally lasts between 14 to 17 days.

Females are normally taken into the yards once a day, early in the morning. Those ewes showing a clear rump mark are separated, while those not presenting heat returns to the paddock with the teaser rams. Ewes in heat are artificially inseminated in the afternoon. However, in order to increase pregnancy rates, two checks in the day are recommended, early in the morning and in the afternoon, with ewes being artificially inseminated in the afternoon and the following morning, respectively. Every two or three days, the painting of the teaser rams is redone.

Fertility rates between 60 and 70% can be achieved with this method [48]. During AI the ear tag of each of the ewes is recorded, in addition to ram number and day and time of AI. After AI, ewes are maintained in a quiet place, with access to food and water, before being taken to their paddock. The use of dogs during all process is normally restricted in order to reduce stress in the animals, which could affect fertility.

5.1.5 Frozen semen artificial insemination

Sometimes, the farmer has the opportunity to import frozen semen from different countries (e.g., New Zealand and Australia due to their good sanitary status, similar to Magallanes). If this is the case, the use of intrauterine laparoscopic AI is the best course of action, with the use of eCG (200–300 IU) as a complementary management, to increase ovulation rate and the number of twins, with higher expected genetic potential. Fertility with frozen semen has been calculated to be over 70% [55].

5.2 Management concepts associated to artificial insemination

Good animal nutrition before and after AI reduces stress, and the farmer needs to consider forage quantity and quality, as well as access to water. Ultrasound pregnancy diagnosis is performed 90 days after AI, in order to check for fertility, but more importantly, to identify single- from twin-bearing ewes. Hence, the latter can be supplemented with a high protein (22%) concentrate to reduce lamb mortality at birth [18], which, under Magallanes environmental conditions, can range from 22 to 62%, being higher in twins [56]. All these managements contribute to increased AI success in Magallanes, making the system more productive and sustainable.

6. Breeding, breeds, and management of sheep production system in Magallanes

Since the second half of the 19th century, the establishment and development of sheep ranching began in the southernmost region of Chile, Magallanes. Large land concessions by the State, and an important commitment from private companies allow an accelerated growth of this industry, being sheep an intrinsic part of the local culture until today.

Natural rangelands in the world, which largely dominate the geography of Magallanes, are those areas used mainly for grazing because they cannot be cultivated. In these large rangelands, the grazing system is "extensive", not only in the sense that it is carried out over large areas, but also because level of inputs, and management of animals is relatively low, with a stocking rate around 0.8 sheep equivalent ha^{-1}.

6.1 Animal and natural resources

The sheep population in Chile is 2,037,516 heads and the 77.1% is located in Magallanes (1,571,056), the southern region of Chile [12]. In this area, sheep production is the most important, and almost the only agricultural industry. It has been developed for the last 145 years (**Figure 3**).

Corriedale is the main breed and represents 55% of the regional stock, just as a purebreed. Some operations have introduced different Merinos, as Australian Merino, MPM (Multi Purpose Merino, developed by an Australian stud, and imported for some breeding seasons into Magallanes), 4 M (Marin Magellan Meat Merino, developed by Marin family in a big sheep operation, from MPM and other Merino lines, and registered officially as the first local purebreed), and most important in recent years the Dohne Merino, and crosses during the last three decades. Because of the increasing value of meat in the total income of sheep business, it is common to see terminal cross use, typically with Suffolk rams but also some Polled Dorset, Texel, and White Suffolk. The regional average weaning percent is below 80%.

Breeding season is in fall, and lambing in spring. The extensive management system with very low inputs, low human intervention, and changing annual climatic conditions leads to erratic results.

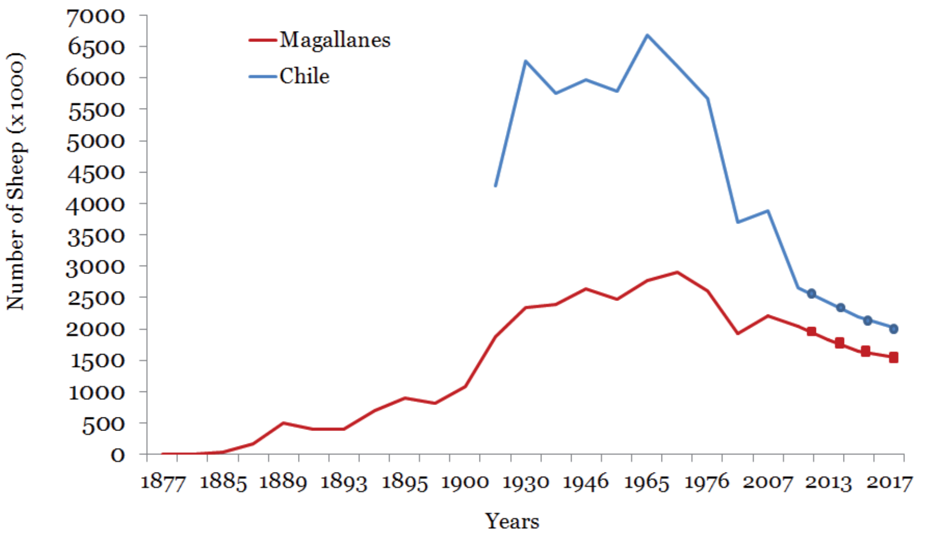

Figure 3.
Number of sheep in Chile and Magallanes region. Dots in red and blue lines counting data between VI to XII region and farms with higher than 60 sheep [7, 12, 13, 38, 39, 57].

Land is owned by medium to large producers. The most common situation are flocks with over 4,000 sheep. The meat and wool market is well developed in Magallanes and strongly oriented to exportation. The region has the potential to increase sheep numbers by at least 30% based on increased production estimates from improving 600,000 ha. of rangeland [58].

6.1.1 Management

Sheep production has traditionally been dual purpose; producing wool and meat, with a carcass average weight for lamb increasing from 10.8 in 1987 to 14.1 in 2020, meanwhile the market is targeting 14 to 16 kg [35].

In this scenario, meat, which at one time in the past was considered a by-product of the wool-focused Magellan sheep industry, today drives the income of sheep

Figure 4.
Herding sheep from summer to winter range, Tierra del Fuego (Image by Oscar Strauch).

ranching in the region. Furthermore, San Isidro Farm (Canepa family) in conjunction with INIA Kampenaike introduced three races of hair sheep (White Dorper, Dorper, Katahdin) in 2012 with a high meat performance.

Sheep operations are based on year-round grazing of private land, with incipient use of strategic supplementation. Most ranches own summer range and winter on separate range (**Figure 4**). Over half do pre-lambing shearing, and lambing is on pasture at springtime.

7. Meat quality

The Magallanes region is not only recognized for its natural parks, such as Torres del Paine, but also for the vast pastoral landscapes and extensive sheep farming developed in this unique environment. The main product is lamb meat, which is exported to different countries, predominately in Asia (China: 45%) and the EEC (Italy: 12%) [59].

Magallanes lamb meat is a grass-fed product that normally comes from young animals (4 to 5 months of age), with an average carcass weight of around 13 kg, raised on natural pastures and maintained, in general, with their mothers until mark time. This gives them a mix of milk and grass nutrition which results in a very interesting product quality. Studies developed by INIA (Agricultural Research Institute), have demonstrated that lamb meat from Magallanes has on average 21% protein content, and a total fat content of 6.4%, which is lower compared to other type of meats. When considering the intramuscular fat (2.5%) and cholesterol (53 mg/100 g), this product may be considered as lean. Tenderness is another remarkable attribute of Magallanes lamb meat, with Warner-Bratzler shear-force results of 1.75 kgf, which positions it as a very tender meat. In addition, it has a similar content for SFA (2900 mg/100 g) to other meats, but a higher PUFA content (628 mg/100 g), compared to some reports in beef. However, the n-6/n-3 ratios (1.3 mg / 100 g) and conjugated linoleic acid (CLA; 25 mg / 100 g) contents represent values that are considered good and desirable from a nutraceutical point of view [60].

7.1 The role of Magallanes lamb meat in human nutrition

The meat of lamb produced in Magallanes is characterized for having a high content of iron (Fe) and zinc (Zn). The average content of Fe for lamb meat in the three different areas of production in Magallanes is 3.9 mg/100 g of meat. This value is significantly higher compared to other meats (**Table 1**). Similar results are observed for Zn content which, with an average of 4.5 mg/100 g of meat, is superior to the Zn content described for other meats (**Table 1**).

Meat	Fe	Zn
Magallanes lamb	3.9	4.5
Foal	3.3	2.4
Lamb	2.3	2.4
Chicken	0.8	1.3
Beef	1.9	4.0
Pork	0.9	2.1

Table 1.
Iron and zinc levels in meat from different species (mg/100 g) [61, 62].

Iron is well known for its role in human health and disease, where deficiencies may result in anemia, leading to functional impairments, affecting cognitive development, immunity mechanisms, work capacity, learning ability, and are associated with increased rates of morbidity. Deficiencies during pregnancy may result in higher risk of sepsis, maternal mortality, perinatal mortality, and low birth weight [64]. According to the WHO [65], the iron requirements of 97.5% of individuals, in terms of absorbed iron, are higher in menstruating women (2.38 mg/day), 12–16 year-old girls and boys (2.02 and 1.92 mg/day, respectively), and lactating (1.31 mg/day) and pregnant woman (1.14 mg/day). Therefore, Magallanes meat lamb consumption is an excellent source for these groups to cover their daily iron requirements.

An adequate intake of zinc has critical impacts for human homeostasis, immune function, oxidative stress, apoptosis, and aging. A deficiency, even mild, may lead to arteriosclerosis and anemia [66]. The recommended daily dietary zinc requirement is estimated at 15 mg/day [67, 68]. The consumption of Magallanes lamb meat could certainly help cover this recommendation. In conclusion, the high content of iron and zinc, the low n-6/n-3 ratio and high CLA content, low cholesterol, and tenderness, make Magallanes lamb meat a healthy food with desirable organoleptic characteristics.

8. Wool production

Magallanes was an adequate location for extensive sheep production when wool was a commodity of worldwide importance. Historically, wool was bought in bulk directly on the farm through private deals, but since the 1980s the system has evolved to prices defined by proper conditioning and bale sampling for wool fineness (**Table 2** and **Figure 5**).

Almost the entire wool crop is exported to a world market dominated by China. The wool exportation of Magallanes 50 years ago was 13,000 tons [70], but decreased to 5000 tons in the 2017 season [57]. **Table 2** shows the price evolution to higher values while wool stocks have simultaneously trended down in recent years with a mean yield of 65% for Standard Wool Company [63] and Agropat[1].

Industry trends towards lamb production and fine wools has changed traditional management from extensive grazing with the dominant Corriedale breed, focused on medium fineness wool production (24.5–31.5 μm and 4.0 kg fleece weight per ewe), to more intensive grazing systems based on dual purpose breeds, focused on lamb production and finer wools. Evaluation and breeding programs to meet shifting market demands have been proposed for different resources availability. In Magallanes there are some Corriedale studs grouped in the Corriedale Breeders Association: El Kark (Kroger family); America (Cardenas family); Jerónima (Vilicic family); Avelina (Menendez family); El Trébol (Maclean family); Tehuel Aike (Almonacid family); Chañarcillo (Gutierrez family); Las Vegas (Retamal family); Maria Isabel (Cavada family)[2].

In Magallanes two new Merino crosses breeds have been registered in the past ten years: 4 M Merino (Marin Magellan Meat Merino – Tres Chorrillos farm by Marin family) and PRM (Patagonian Robertson Merino – Tres Hermanos farm by Robertson family), both aiming for finer wool (17–22 μm) and heavier lambs, while maintaining the hardiness of Corriedale. For another side, Dohne Merino has been introduced successfully in the region by Hugo Vera in 2004 (Josefina farm), and has

[1] Cecilia Cavada, Agropat Ltda, Punta Arenas.
[2] https://www.asogama.com/los-planteles; Peter Maclean (El Trébol) and Cecilia Cavada, Agropat Ltda.

Season	Greasy Wt.	Yield	Clean Wt.	Clean price	Greasy Price
	M.T.	%	M.T.	US$	US$
1998/9	5362	62	3324	1.43	0.89
1999/0	6723	64	4303	1.47	0.94
2000/1	6530	65	4245	1.58	1.03
2001/2	5551	64	3553	1.80	1.15
2002/3	5852	66	3862	2.88	1.90
2003/4	5432	66	3585	3.10	2.05
2004/5	5714	65	3714	2.66	1.73
2005/6	5808	63	3659	2.25	1.42
2006/7	5943	64	3804	2.37	1.52
2007/8	6208	65	4035	2.84	1.85
2008/9	4920	65	3198	2.29	1.49
2009/10	5558	65	3613	3.34	2.17
2010/11	4789	65	3113	4.55	2.96
2011/12	4324	65	2811	6.08	3.95
2012/13	4534	65	2947	5.37	3.49
2013/14	4682	65	3060	5.54	3.62
2014/15	4557	65	2951	5.63	3.65
2015/16	4923	64	3130	5.43	3.45
2016/17	4421	63	2793	4.80	3.03
2017/18	4866	64	3102	6.15	3.92
2018/19	4570	65	2971	8.00	5.20
2019/20**	2524	65	1641	5.67	3.69
2020/21**	2749	65	1787	3.50	2.28

*M.T. = metric tons. **In these seasons, many farmers did not sell their wool production for low prices, because of the pandemic situation.*

Table 2.
Price, yield, and wool stock purchased by Standard Wool Cia. from 1998 to 2021 [63].

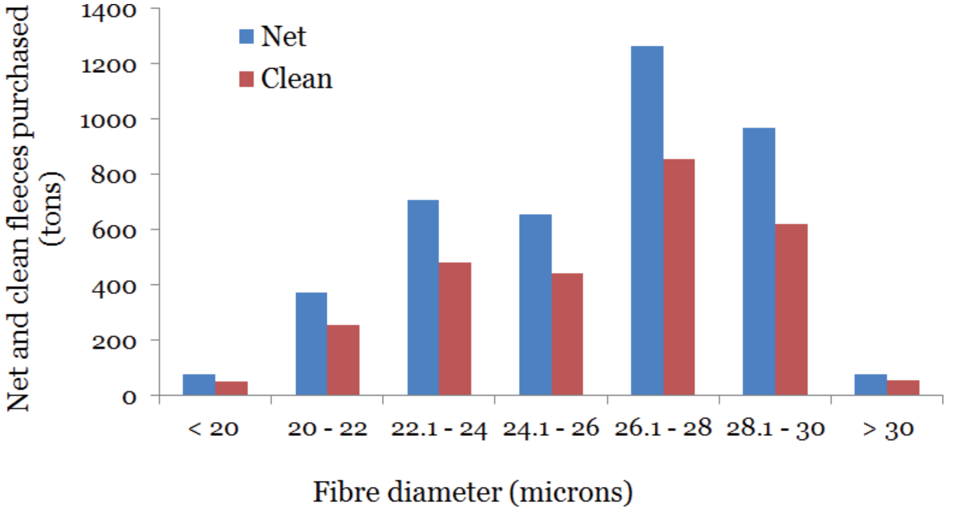

Figure 5.
Net and clean wool purchased according to fleeces fibre diameter (season 2018/2019) [69].

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Figure 6.
The traditional shearing process in Magallanes, different process stages from A to J. (Image by Sergio Radic S.).

resulted in higher profitability on some farms in comparison to traditional breeds [71]. **Figure 5** show fleeces fibre diameter for one season, highlighting the range 26.1 to 28 microns as the main diameter in the region.

Shearing practices have also changed to include two options: (a) traditional timing of post-lambing shearing from the end of December to February; (b) pre-lambing shearing in late August and September. The pre-lambing shearing with positive results in lamb marking, lessened ewe mortality [69] and cleaner fleeces [35], this management arrived late in 80′ by the farmers Carlos García and Ivo Robertson. The tally-hi shearing method used in Magallanes was upgraded by New Zealand technicians. The shearing process starts with animals separated in a corral (**Figure 6A**) into different categories, and then they are moved into the shed (**Figure 6B** and **C**). Subsequently the sheep are sheared (**Figure 6D** and **E**), fleeces are cleaned on a table (**Figure 6F**) and placed into the wool press (**Figure 6G**) to build the bale (**Figure 6H**), and finally the wool bales are placed all together where each one has a note with a description of wool type and farm name (**Figure 6I**) and the ewe is released to outside (**Figure 6J**).

9. Lactation curve and cheese production

There is one dairy sheep operation that was set up as a pilot program in the 1990s by the University of Magallanes (coordinated by Sergio Kusanovic) in the city of Puerto Natales (Chilean Patagonia). The program uses East Friesian sheep (from

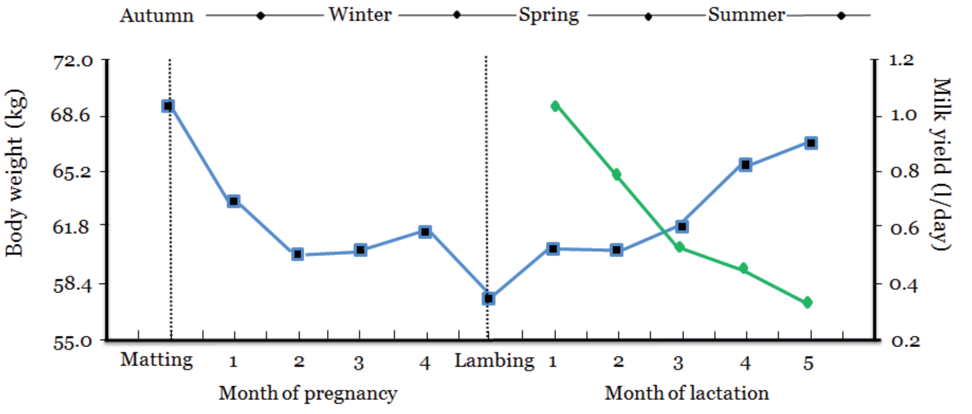

Figure 7.
Milk yield (dotted green line) in lactation period and body live weight (solid blue line) during the year of East Friesian sheep [72].

Bolson city in Argentina) and was developed with the goal of cheese production at a local scale. The lactation curve (**Figure** 7) and cheese production is based on grassland grazing and strategic supplementation with 200 g d^{-1} of commercial concentrate (15% CP; 2.6 Mcal EM kg DM^{-1}) from flushing two weeks prior to breeding through the breeding period. The sheep are fed under a grazing system in the first 100 days of pregnancy. For the last 50 days of pregnancy, 400 g DM d^{-1} of alfalfa hay is supplemented [73]. Because the nutritional management is mainly by grasslands, it is a way to develop organic farming, a production method with a specific market focus on products of premium quality and high standards [72].

The feed ration and body reserve are very important inputs for adequate milk yields in dairy sheep at the end of pregnancy and during lactation. For the latter, in systems that base their feeding management on grasslands, body weight at pregnancy, lambing and lactation may be considered indicators of animal nutritional status and body reserve level.

This initiative developed by the University of Magallanes produces the southernmost cheese of Chile. The higher concentrations of fat, total solids and protein (6.2%), present in sheep milk compared to goat (3.4%) and dairy cattle (3.2%), result in high yields in the production of dairy products [74]. There is a possibility to generate a brand image with this kind of cheese in the Chilean Patagonia. The commercialization of sheep cheese in Magallanes traditionally corresponds to consumers of foreign origin, but also markets to gourmet stores, hotels or restaurants, where there is the highest consumption [75].

10. Best livestock practices and animal welfare in Magallanes

In a highly globalized world characterized by increasing demands by the large international markets, the Magallanes region has some intrinsic advantages, including its geographical location, associated with characteristics of extensive production that allow for reducing the risks associated with animal welfare. Although this system minimizes human-animal interactions (limited number of operations and/or contacts)[3], livestock should be managed and overseen by capable personnel to ensure the correct execution of management and create a positive human-animal interaction.

[3] At least three times per year, for operations (shearing, branding, and breeding).

Although the concept of welfare refers to a state of physical and mental health where the animal is in complete harmony with the environment that surrounds it [76], today we focus on "one health", a concept that entails good management and animal care that leads to good human health and positive collateral outcomes, both economic and social [77].

Animal welfare today is structured on five fundamental domains: adequate nutrition and water availability, health and disease prevention, good environment and provision of opportunities, behaviors and freedom to express them, and finally, mental state, which is determined by the experience of the four former domains, logically resulting in both negative and positive parameters. The complex part for extensive production systems is to find the right moment(s) to apply practical, quick, valid, reliable, and repeatable measuring techniques (direct and indirect indicators, based on the resources or the animal, to evaluate its state and condition) to generate an accurate picture of sheep production today in the Magallanes region.

In order to ensure a livestock sector that is both sustainable and adheres to both national (Law Chile 20380, decree-law numbers 28–29-30) and international requirements, rules, and regulations, the sheep industry, farms and livestock personnel are slowly but satisfactorily developing changes in some practices, especially those related to animal handling and painful procedures (tail docking, castration), where the Good Livestock Practices manual is one of the first to be generated on this subject in the region. It is essential today to have plans that allow for storage of adequate food and water supplies, constant health monitoring, and adequate facilities to minimize and facilitate animal handling in delicate procedures such as transport, herding, and shearing, among others, as well as allowing the manifestation of both natural and normal behaviors during production processes.

Finally, it is highly recommended that the personnel working in production units know and understand the concepts related to sheep management and production, which will result in adequate competence, minimizing risks, injuries and potential processes that generate negative effects in the production chain.

11. Sheep farming and wildlife interactions in Magallanes

The relationship between wildlife and animal production involves ecological interactions such as competition for foraging resources and space, and predation [78]. Wildlife-livestock interactions are mostly assumed to be detrimental to human economic activities, leading to wrong attitudes and prosecution of wild species in areas of coexistence with livestock [78]. The situation of sheep ranching in Magallanes is not different; sheep either compete with wild herbivores or are killed due to carnivore predation. Therefore, producer views towards wild species are generally negative [79, 80]. However, despite the economic importance of sheep production in Magallanes, studies about sheep interactions with wildlife are rather scarce, with more information from Argentinean Patagonia [81, 82].

When sheep ranching arrived in southern South America in the late 19th century [83], guanaco (*Lama guanicoe*), a large South American camelids and the main wild herbivore of the Patagonian steppe, numbered between 7 and 10 million individuals [84]. Since that time, guanaco have been considered the main competitor for sheep by ranchers [85], and their numbers declined to about 600,000 animals by the end of the 20th century. They currently occupy less than 40% of their original range [86]. The decline in guanaco abundance and distribution is associated with high numbers of sheep and resulting reduction in preferred forage [85]. Extensive sheep ranching seems to have produced an increasing degradation of guanaco habitat due to overgrazing, changes in the structure and composition of vegetation, displacing guanaco and changing their distribution [87]; however, sheep-guanaco interaction outcomes are still controversial [88, 89].

Available information is mostly limited to dietary composition of both species, indicating a large overlap in food items [81, 90]. It is assumed that this large herbivore consumes great amounts of vegetation, the equivalent of two to three sheep. Camelids, however, have low metabolism rates, implying lower food consumption, so the opposite situation should be considered [91]. Although ranchers in Magallanes do not place an economic value on guanaco, they are perceived as an obstacle to domestic sheep production [79]. There are efforts from Chilean government agencies under the Ministry of Agriculture to support the sustainable use of guanaco [92]. After several years of guanaco counts, annual hunting quotas under 3% of estimated guanaco population have been established to give guanaco economic value [92]. Currently, the guanaco population inhabiting productive lands in Magallanes is estimated at 297,844 individuals [93].

Other wildlife that might use similar food resources and space with sheep are herbivorous birds like the lesser rhea (*Rhea pennata*; [94]) and wild geese (*Chloëphaga* spp) like the upland goose (*C. picta*; [95]). However, these herbivorous birds are not seeing as competitors like guanaco because of their smaller size and lower conspicuity. Nonetheless, there is a lack of studies on wild birds interacting with sheep ranching in Magallanes and most of information occurs in Argentinean Patagonia [96] and the Falkland Islands [95].

Similarly, since the advent of sheep ranching in southern Patagonia, large predators, like puma (*Puma concolor*), and meso predators, like culpeo (*Lycalopex culapeus*) and gray foxes (*L. griseous*), have been interacting with sheep ranching in rural Magallanes [97]. This interaction with wild native carnivores generates economic losses to ranchers because puma and foxes are a source of sheep mortality. Additionally, the attack and predation of sheep by domestic dogs is a growing concern worldwide, and Magallanes is not an exception. In Chile, domestic dog predation on livestock lacks legal regulation.

According to official government records, carnivores impact animal production in Magallanes [98]. Between 2012 and 2017, 2259 livestock animals were killed by carnivores, 83% of which were sheep (1887 head) [98]. The majority of those attacks were reported on the Island of Tierra del Fuego (59%). If reported attacks are organized by predator species causing mortality, 78% of attacks corresponded to domestic dogs (55 events) accounting for 1855 predated livestock (82%) [98]. Foxes (*Lycalopex* spp) were reported to predate 208 livestock (9%), and puma predation on livestock was 1% (13 animals) [98].

Farmers hunt native carnivores despite this activity is illegal in Chile [80]. This situation could be associated to the lack of governmental programs to verify livestock mortality causes and issue compensation of economic loss [80]. Recently, sheep ranches near Torres del Paine National Park, one of the main protected areas in Magallanes, have changed their perception of puma because the presence of this large carnivore is a source of an important touristic activity in the area producing important economic revenues [80]. Other animals that are perceived as harmful for sheep farmers include raptors like southern caracara (*Caracara plancus*) and buzzard eagle (*Geranoaetus melanoleucus*), which predate on newborn lambs [99], but there are not formal reports from Magallanes.

It is necessary to differentiate sheep losses because of wildlife from those caused by deficient ranch management. Several sheep ranches seem to have incorrect estimates of appropriate stocking rate density that can cause overgrazing and degradation of the steppe that finally drive to poor animal conditions and economic losses, which is not directly related to the presence of wild herbivores. The importance of large carnivores in overall ecosystem health must be considered before lethal control. Predation prevention methods like night shelters or guard dogs, should also be used where appropriate [100].

12. The agritourism potential in Magallanes: Farm tourism or tourism on farms?

The farms in the Magallanes region have been characterized by developing and preserving an extensive infrastructure, consisting of numerous interrelated buildings to meet the demands and services of a sheep farm, which has historically been extensively developed [101]. Usually the farms are huge estates, hundreds or thousands of hectares in size, and in many of them there are still tools, machinery and furniture typical of the colonizing era from the mid-19th century to the early 20th century [102]. These locations are nestled within natural landscapes that include lakes, rivers and wide landscapes such as the Patagonian steppe, where the horizon and the sky display dramatic sunrises and sunsets. Furthermore, prior to the establishment of these ranches, these sites were inhabited by ancestral peoples who knew the territory and its resources very well [103]. All these conditions provide an ideal setting for agritourism [104] as a way to combine culture, nature, leisure and recreation in a landscape experience.

Tourism on farms in the Magallanes region is emerging and poses opportunities and challenges to innovate in regional economic development. Currently, the offer for tourism on estancias is traditional and restricted to activities typical of nature tourism such as wildlife observation, walks, horseback riding, photography and fishing, among others. To a lesser degree, activities typical of agriculture (**Figure 8**) are available, such as organic agriculture and observation of traditional tasks such as sheep herding or shearing, among others. Often, but not always, this offer is associated with spending the night in the manor houses itself and tasting local cuisine, so that the experience is complemented by the charm of the architectural heritage and historical legacy [101]. However, this type of tourism faces endemic problems such as seasonality, lack of specialized human resources and poor connectivity. Usually the distances are exaggerated, the accesses are tortuous, and even in many of them digital connectivity problems persist, which makes it difficult to implement online

Figure 8.
a) Herding of sheep in Magallanes, one of the favorite activities to observe by tourists in estancias in the region (image by Claudio Vidal). b) Sheep bath, as another interesting farm task for tourism (image by Sergio Radic K.).

marketing and reservation systems, resulting in a loss of service. In addition, many times the tourist product offered is limited to passive observation experiences, but the tourist storytelling to enrich the visitor's experience and feed their learning and interest, is absent. Thus, this type of tourism wanders between "farm tourism", where the central activities are related to the ranch trade [105], or "tourism on farm", a farm where tourist activities other than the traditional.

Today, the particularities of the tourist atlas of the Magallanes territory can be considered counterproductive for the development of farm tourism in isolated areas. The profitability of agritourism as such is low and occurs as a complementary element to other economic activities, but it is not the main one [106]. Tourist concentration is persistently monopolized and overshadowed by Torres del Paine National Park, considered by many to be the gem of Patagonia and the main pole of attraction for regional tourism [107]. Thus, perhaps a relevant option would be the diversification of tourism content on the basis of local identity; generate a local identity to offer a different product, where tourists enjoy and learn about distinctive aspects such as architecture, history, ethnography and rural life. This identity could be re-created from and for the territory, starting from the cultural histories and the memory of the ancestral peoples. There are numerous ethnographic, historical, architectural and family resources [103, 108, 109] to implement a touristic storytelling and generate an "experience scape", as has happened in other areas of farm tourism [110]. However, tourism research is required to consolidate facts, protagonists, sites and narratives for a continuous valorization of the cultural and natural heritage with potential for the development of tourism, whether it is for farm tourism or tourism on farms.

13. Final comments

After 145 years of sheep production, the Magallanes region has become a characteristic and important territory for sheep industry, and must continue to improve the quality level of products demanded by consumers. Three key points lead the future of the industry in the region: sustainable management, markets, and human resources; but the ability to integrate all these points in the same direction will support farm success. Through technology adoption and sustainable management practices, the industry can achieve soil, water, and grassland conservation and utilize best livestock practices that improve animal welfare and sheep-wildlife interactions. Improving and/or intensifying utilization of a small percentage of each farm (approximately between 2 and 5% depending mainly to stocking rate used and the dry matter production of grasslands) will achieve sustainable and profitable long-term production. Considering the economic side of production in the region, the market currently demands lamb carcasses around 14 to 16 kg and finer wool, between 17 to 22 μm. Then, each decision making must consider existing management and farm production system (meat, wool, or dual purpose) and quality product that can be produced. Broadening market potential through diversification is an important consideration, but must be evaluated within the context of each farm, in this way tourism, dairy products or knowledge of ecosystem services could play a significant role. Finally, human resources need to be specialized to face these challenges, for which technical abilities, undergraduate and postgraduate studies are a key component. The Agricultural and Aquiculture Sciences Department of Magallanes University and the Agricultural Research Institute (Kampenaike Experimental Station) will have an important role in disseminating technical knowledge and providing professional development in our region.

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Conflict of Interest

The authors declare no interest conflict.

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Chapter 2

Retrospective Study of Production and Commercialization of Sheep Wool from Mexico

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Abstract

The purpose of this chapter is to provide information on wool production from Mexico in a period from 1980 to 2019, addressing some of the problems faced by the wool market over time. An analysis of variables such as national production of wool, cost of kg of wool, import and export of wool was performed with the aim of having a complete picture of the situation in Mexico. Also, the production of Mexico was compared with that of other countries that occupy the first places in wool production and quality, to have a starting point and propose improvement scenarios for the production of Mexican wool production. Overall, wool production in Mexico cannot cover the national demand, having to resort to the import of this product. The use of native resources of the region, such as the "Chiapas sheep breed" allows the development and maintenance of traditional ancestral culture, such as the Tzotzil, and the manufacture of handicrafts typical of each of the regions of Mexico. However, the management of long-term programs through the inclusion of dual-purpose breeds, wool, and meat can be a viable alternative for the development of the wool industry in Mexico.

Keywords: sheep, fleeces, wool quality, fibers

1. Introduction

The sheep have been raised throughout history to obtain three products—meat, milk, and wool. The leather is traditionally used for the manufacturing of shoes, jackets, and gloves, competing with synthetic products and with a downward market in recent years [1]. In the case of Latin America, from 2000 to 2016, sheep and lamb production has shown a slight decrease from 82,603 to 77,915 heads [2]. Throughout the years, sheep that produce wool have been selected to produce mainly meat; however, the Mediterranean countries have also been in charge of potentiating sheep milk production [3]. Wool is an animal product that is used by the textile industry; Botha and Hunter [4] indicated that approximately 56% of global wool production is used for clothing, 42% for home textiles (interior design), and 2% for industrial applications. It should be noted that natural fibers, such as wool, globally accounted for 3% of total fiber production in 2013, similar to coconut fiber. Wool is still an accessible product, in high demand and with excellent prices, depending on the type of wool, but the most important thing about this natural fiber is that it is biodegradable without having a negative impact on the environment [5, 6].

1.1 International situation of wool production

In the textile industry, wool has been replaced by synthetic fibers due to its quality, price, and diversity. As a consequence, the world's number of sheep and wool production declined [3]. The amount of wool production in the market had a decline of 11.7% from 1990 to 1996 due to the large quantities stored for years by the main world producers (Australia, New Zealand, and South Africa). These were put on the market, generating a sharp decrease in the price and causing a decrease in the income of wool producers [7]. In spite of this, in 2002 the price of wool increased due to lower global production, due to the decline of the sheep population worldwide, the decrease in the Australian sheep stock, the increase in fiber prices, and the decline in cotton production worldwide [8]. In summary, wool production decreased globally due to a fall in the sheep inventory, sacrificing the number of animals for meat marketing consumption; the production of superfine wool breeds was privileged, and only increased production was shown in the main producing countries, such as South Africa, Uruguay, and Mongolia, in the 2013–2014 period [9]. The rest of the countries globally have not shown an increase in the number of animals for wool production and wool marketing.

It is noteworthy mentioning that although wool production represents around 3% of the global fiber production, it represents an income of 8–9 trillion dollars per year, just below cotton that has 45 trillion dollars, and coconut fiber that has an income of 0.4 trillion dollars. Even though the production of coconut fiber is like that of wool, economically speaking, wool is more profitable than other natural fibers. One example of this is that clean wool can reach a price of $ 7.3 USD/kg, followed by silk ($ 4.4 USD/kg) and cotton ($ 1.7 USD/kg) [10].

1.2 The production of sheep wool in Mexico

Currently, in Mexico, there is an inventory of sheep farming of approximately 8 million heads [11]. The sheep production is distributed in three regions—in the central region for meat production, there are wool breeds, such as Suffolk, Hampshire, Rambouillet, Dorset; hair-sheep (Katahdin, Dorper, and Pelibuey) in the south-southeast region is mainly based on hair-sheep breeds (Pelibuey, Black Belly, Katahdin, and Dorper); and in the northern region which used to be the main supplier of wool, it has recently introduced hair-sheep breeds (Pelibuey, Katahdin and Dorper) for meat production [12, 13].

In Mexico, wool production in 1996 showed a decrease of 13.5%, as in the rest of the world. In the following years, there was a recovery in production, increasing by approximately 26% (5042.18 tons in 2012) [14]. Recently, wool production in the country has been negatively affected by two factors, firstly, Mexico has prioritized the production of sheep for meat and, secondly, producers have stopped being interested in the production of sheep. As a consequence, wool production is only used for handcraft purposes in some states of Mexico [15]. Medrano [16] mentioned that by 1999, it was estimated that around 50,000 producers nationwide were engaged in sheep farming, and only 120,000 artisans worked with wool. In 2007, [17] it was reported that only 37% of the total heads of sheep were used for wool production. These data revealed the socioeconomic importance of sheep in Mexico.

For marketing purposes, wool fibers are classified based on—fine wool (Merino wool), medium wool, long wool, crossbred wool and carpet wool; secondly wool fibers are classified depending on the fiber length in Noels, strictly combing, French combing, clothing and carpet wool. Finally, wool fiber is classified on the age of sheep (Lamb's wool, Hogget Wool, Weather wool, Pulled Wool, Dead Wool, Cotty and Taglocks). This process is essential since there is great variability between sheep breeds, and even within the same breed, the different body regions of an animal, as well as the colors (being white color the most relevant for the textile industry because it is easier to dye) [18].

Mexico has coarse wools which, in some regions (the municipalities of "Temoaya" and "Guadalupe Yancuictlalpan," in the state of Mexico and "With the Tzotzil community" region in the state of Chiapas, Oaxaca), continue to be used for handmade textiles manufacturing. The community of Guadalupe Yancuictlalpan, also known as "Gualupita," located in the state of Mexico, is one of the few places where this activity is still carried out. In these regions, the product called "sarape" or "gaban," "chamarro," "jorongo," which simulates a blanket with a hole in the center, to introduce the head, is still produced and is typical of the clothing of the people who work in the fields on cold nights of mountains and deserts. However, it has been negatively affected by the increase in production costs and the scarce promotion of its handcrafts [19]. Another example is the work carried out by the Tzotzil women located in the mountainous region of the state of Chiapas, whose purpose of raising sheep is an important subsistence strategy, since sheep are used for traditional garments for women wearing their black woolen skirts and their richly embroidered brown blouses, and they cover themselves with black shawls. Children's clothes, blankets, and bedspreads are woven to blend fleeces of different colors, to create an infinite number of gray and brown shades. These woolen clothes are quite heavy and a hairy finish is highly regarded; they are also waterproof and last a very long time—2 or 3 years of daily use and of course handcrafts (wool dolls, skits, sweaters, bags, etc.) that are sold to tourists [20].

Therefore, the objective of the present study is to evaluate the production of wool in Mexico in a period from 1980 to 2016 and compare it with some producing countries and generate some scenarios about its possible commercial development.

2. Material and methods

The methodology consisted of a literature review, covering both scientific and technological documents and data from official sources from 1980 to 2019 regarding wool production in Mexico. Also, relevant information on the international market, such as costs, production, imports, and exports, was included.

The obtained data was analyzed as a retrospective and longitudinal study considering the following variables—number of animals, tons of wool produced, tons of wool imported, tons of wool exported, cost of kg of wool in US dollars, yield, and national per capita economic income. Then, a database was built, and three scenarios were proposed.

The first scenario is an overview of the national production of wool, considering the price of kg of wool and the number of animals reported by the Mexican state (INEGI) [17].

The second scenario is a picture of what would be the case if all sheep were sheared and all wool was commercialized, assuming that the sheep population was 100%, wool producer.

The third scenario is focused on recommending genetic improvement of sheep breeds to convert them into dual purpose and with this, not to neglect the meat market, but in turn, increase profits for the producer and improve the country's wool market.

It is important mentioning that these scenarios are hypothetical and depend on certain variables, such as race, animal handling (all zootechnical aspects), price, wool production, and fleece quality (color, diameter, length, resistance, number and type of curls, and elasticity).

3. Results

3.1 Number of heads of sheep

According to the Mexican Agrifood Information System [21], the national inventory of sheep has shown an increase of 34% from 1980 to 2019 (6,482,200 and 8,708,246 respectively), considering the variations and economic changes that were experienced in the country (**Table 1**).

The variations discussed above can be observed when comparing the human population with the sheep population (**Figure 1**), showing that in 1980 for every 11 persons there was a sheep; for 1990, the number of sheep decreased by 9.8% compared to the previous year, and finally, for 2016, the number of animals increased as did the human population, giving a ratio of 14 persons per sheep. This confirms that sheep production has not had a great development through the years analyzed in this study. This is also in agreement with Ramírez [22], who reported an annual average growth rate of 0.85% between 1980 and 2016 for the sheep population.

3.2 Production of sheep wool in Mexico

In the case of wool production and market, it can be observed that the quantity of wool produced in the country has been drastically decreased. Compared with 1980 wool production, in 2016 that was decreased by 26%. Regarding wool imports, the year that showed more imported tons was in 1980 and in 2016, only 4854 tons were imported, representing 31% less compared to 1980. The opposite happened with exports since in 1980 there were no exports, but in 2010, 510 tons were exported (**Figure 2**).

The producer price has been reduced, presenting the best price (USD $ 2.00/kg wool) in 1990. Subsequently, wool price has been decreasing by 87% from 1990 to 2019 (USD $ 2.00/kg vs. $ 0.26/kg, respectively). When considering the number of animals and total wool production, it can be seen that although the number of sheep heads has increased yearly, wool production does not grow at the same rate (**Table 1**). It confirms what was previously reported, where Mexican sheep production focuses

Year	Number of animals	Wool production (ton)	Wool price US $/kg
1980	6.482.200	6554	1,47
1990	5.846.000	4517	2,00
2000	6.045.999	4176	0,587
2010	8.105.562	4683	0,282
2016	8.792.663	4854	0,27
2019	8.708.246	4015	0,26

Table 1.
Sheep population, wool production, and price of wool (US Dollar) in Mexico.

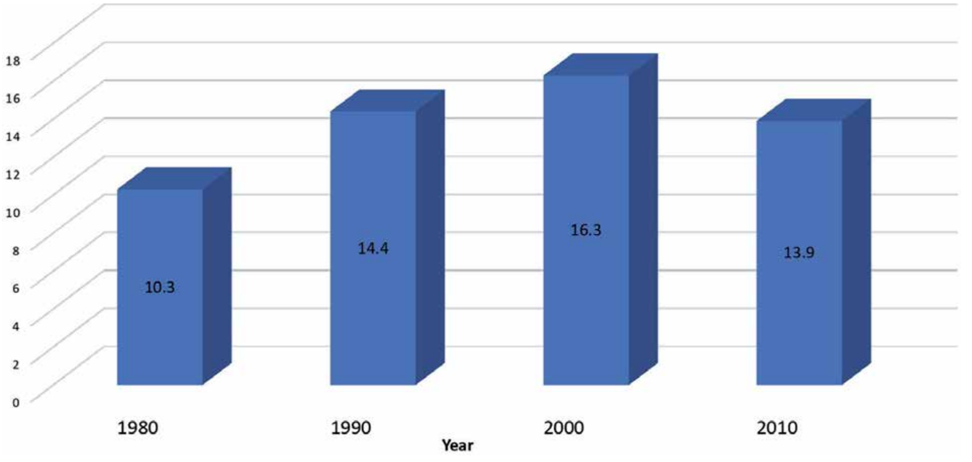

Figure 1.
Relationship of the human population in Mexico/number of total sheep from 1980 to 2010.

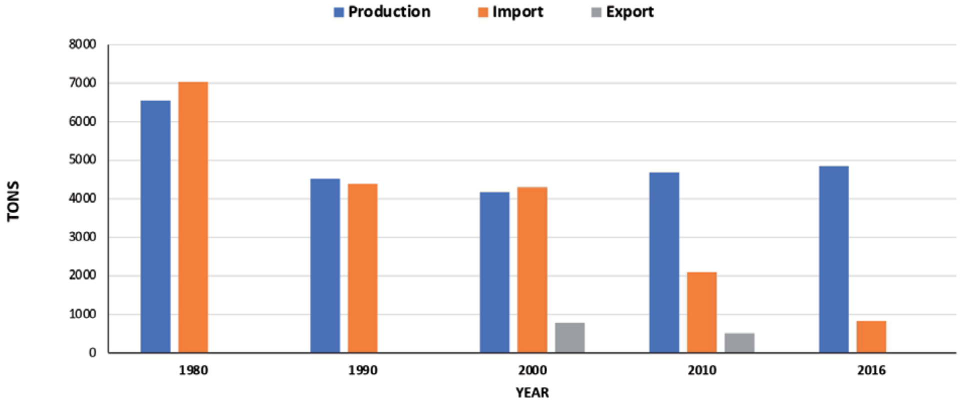

Figure 2.
Production (), import () and export () (tons/year) of wool in Mexico.

on meat, subtracting attention to wool production, which unlike the rest of the world seeks to obtain longer and finer fleeces. In Mexico, the use of crossbreeds gradually eliminated the wool of these and turn them into hair breeds (i.e., Pelibuey, Kathadin, and Blackbelly) [23].

States, such as Hidalgo, Oaxaca, Chiapas, Zacatecas, State of México, and Tlaxcala, are known for having a period of shearing of meat sheep that has given rise to their wool textile production. There are some wool groups in the country that have managed to survive. In mid-2010, associations, belonging to the cities of Guanajuato, Toluca, Tulancingo, and Chignahuapan, were organized to market and improve the value of national wool, through the selection and packing of wool from sheep meat breeds of various qualities to be exported to Uruguay [23].

3.2.1 Scenario 1

When considering the percentage that INEGI [17] published in 2007, we could assume that only 2, 999,058 sheep, 37% of the total population of the year 2010, was used for wool production, obtaining 4683 tons at a cost of USD $ 0.28/kg (in 2007), leaving USD $ 1, 311,240 of income for the total wool produced. When reviewing the FAO data [2], they indicated that imports of wool (dirty, clean, and waste) for

Mexico were 2099 tons at a cost of USD $ 9,425,000 where the price per kg was USD $ 4.49. It can also be noted that 42% of wool imports has a very poor quality, which was used for handmade textiles that were then exported (**Figure 3**) as a handcraft.

3.2.2 Scenario 2

If all the sheep that exist in Mexico were sheared, assuming that instead of 37% of the sheep population was 100% that which is used for wool production, we could say that the production in 2010 would have been 12,657 tons, with this figure would probably decrease considerably the amount of imported wool and increase the profit of the producer since, as mentioned above, not all imported wool is of good quality and producers who have dual-purpose animals would have a market for selling their wool. For this to take place, it is necessary to standardize the price to the producer per kg of wool and train them so that the shearing is annual and correct and then it could be possible for the producer to be interested in the market and obtain an extra income. Considering the previous points, if the payment of wool per kg was modified, it could be more attractive for the farmer producer. For example, New Zealand, where in the year 2010, the average price was USD $ 2.27/ kg wool (8.1 more times than in Mexico), which increased the interest of farmers producers shearing their sheep annually to obtain approximately 2 kg–5 kg of wool [24] with a profit of USD $ 4.54–USD $ 11.35/kg sheep. In Mexico, this would make a big difference in the national market. This is hypothetical because not all sheep are wool-producing breeds, nor is all wool produced from sheep utilized. In fact, in Mexico, most wool is discarded and not sold by the farmers.

3.2.3 Scenario 3

The wool market should be attractive and consistent so that farmers stop seeing the wooly breeds as a "problem to shear" and become an opportunity and an extra income for the farmer.

In **Table 2**, in 2010, countries, such as Australia, New Zealand, and Uruguay, obtained a total annual income (wool production plus sheep meat production) of USD $ 3,469,145.48; USD $ 1,713,571.57; and USD $ 240,303, respectively, in which, income from wool production, covered 42.7% in the case of Australia, 23.35% for New Zealand, and 49.24% of income in Uruguay. If we compare the results of these countries with those of Mexico, it can be noted that Mexico's total income is not

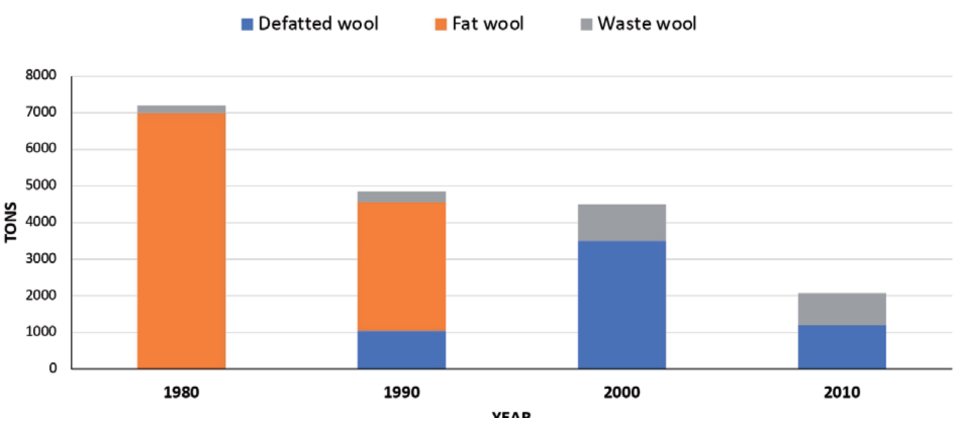

Figure 3.
Import of wool (tons) in Mexico from 1980 to 2010 (defatted wool, fat wool, and waste wool).

Country	Number of animals	Meat production (ton)	US/kg meat	Income from meat production	Wool production (ton)	US/kg wool	Income from wool production
Australia	68.085.496	555.206,00	3,58	1.987.637,48	352.740,00	4,20	1.481.508,000
New Zealand	32.562.612	474.141,00	2,77	1.313.370,57	176.300,00	2,27	400.201,000
Uruguay	7.710.000	31.600,00	3,86	121.976,00	34.700,00	3,41	118.327,000
Mexico	8.105.562	54.966,00	3,64	200.076,24	4.683,00	0,28	1.311,240

Table 2.
Income from meat production (US Dollar) and wool production in different countries during 2010.

Countries	Number of animals	Wool production (ton)	% Fine wool (18–26 micron range)	% Fine wool (27–40 micron range)	Relation kg wool/sheep
Mexico	8.105.562	4.683	No information	No information	0.0006
Uruguay	7.710.000	34.700	35%	65%	0.0045
Australia	68.085.496	352.740	88–90%	12–10%	0.0052
China	134.021.218	272.000	70%	30%	0.0020
New Zealand	32.562.612	176.300	80–90%	20–10%	0.0054

Table 3.
Sheep population and wool production in different countries (2010).

Figure 4.
Proud Tzotzil women with their lambs (white/black).

very different from that of Uruguay. However, income from wool production only reaches 0.65% of the total income. If the wool production mentioned in scenario two had been obtained, and the price per kg was modified, taking as reference New Zealand (it is the country that showed the lowest price per kg of wool) we could reach a total income of USD $ 228,807.63 where 12.55% of the total income would be for wool production. This would result in an increase in the income of both the country and the farmer producer. **Table 3** shows the percentages of the type of wool produced by the main producers worldwide. Australia, besides being the country that produces the most wool, also produces the largest amount of fine wool. In Mexico, there is no official information that indicates the percentage of fine wool produced in 2010, it can only be said that the amount is medium thickness, used to make handicrafts.

If a policy is achieved to encourage or subsidize support for genetic improvement and obtain animals with better production and quality of wool without neglecting the production of meat (main market in Mexico) could be reduced and probably eliminate the import of wool waste in Mexico.

In some Mexican states, there are wool breeds, such as Rambouillet to Australian Merino, Deboullet, and Lincoln, which have been crossed with breeds that have a good daily weight gain, such as the Columbia breed [25]. On the other hand, the Corriedale breed could be introduced to maintain quality and, like the previous one, not neglect the production of meat. However, to achieve this, it is necessary for farmers to be trained and oriented so that there is a "regression" and their attention is focused on the breeds that have existed for many years in Mexico such as the Chiapas sheep breed (**Figure 4**) [26].

4. Discussion

4.1 Number of heads of sheep

Mexico has a great diversity of climates (temperate, humid, and dry), very rugged topographies (hills, mountains, desert, and rain forest), and different economic levels, which makes the production of sheep a favorable alternative (**Figure 1**). Mexico has become more dependent on imports in program crops and meat/livestock between 1986 and 1998, where agricultural activities, such as corn, soybeans, wheat, cotton, rice, beef, pork, and poultry, have increased [21].

Sheep production in Mexico has undergone several changes over time and it is very evident that the growth has been slow. From 2010 until 2016, the number of heads has only increased by 8%, unlike the period of 2000–2010 in which there was a growth of 35%. This could be due to the production objective that each Mexican state has and that the majority of sheep producers are oriented to subsistence farms [15].

4.2 Production of sheep wool in Mexico

The national wool production shows a decrease through the years, being 1980 with the greater production unlike 2019 when the quantity of tons decreased up to 38%. Possibly this may be because sheep breeders have tended to replace the wool breeds with those that do not need to shear, leaving aside the wooly breeds and substituting them for breeds of hair (i.e., Kathadin, Pelibuey, and Blacbelly) or their crosses between these two, which is an advantage due to the low prices of wool and the lack of specialized labor [24].

It is important to mention that about 80% of the sheep registered with AMCO (Asociación Mexicana de Criadores de Ovinos) are of hair breeds and the rest of breeds. This proves the aforementioned [24], so there is an increasing decrease in wool breeds and a much bigger gap in specialized wool breeds, except for the native breed of Chiapas, where it is kept as a dual-purpose breed (meat and wool), for the production of clothing and handicrafts typical of the Tzotzil culture (**Figure 5**).

Another reason why wool production may be decreasing is the cost/benefit ratio of sheep producers, as the breeds are not specialized in wool production, the quality of the wool is very variable and its commercialization in certain areas is not profitable, including the shearing process.

The costs of shearing fluctuate between \$ 3.5 and \$ 4.5 USD per sheep and the shearers take all the wool as part of the profit and therefore, many farmers prefer to throw the wool sheared by themselves [27] than selling it. Finally, another factor is the intermediary or the lack of a direct marketing channel, which buys wool from sheep producers at very low costs, sometimes paying up to an average of USD \$ 0.10 per kilo of dirty wool, which is why they opt for had another alternative as a hair sheep breeds, and another factor that could affect the wool market is the issue of little diffusion and the loss of customers who have suffered wool crafts. The few localities that still have the habit of teaching and practicing the elaboration of handicrafts, increasingly tend to be less visited [19]. On the other hand, since the United States of North America is the main buyer of wool products (99% of the product), the market is affected when demand decreases, as it did in 2009 [28]. It is important

Figure 5.
Evaluation of wool by Tzotzil women on the live animal, to see that they are ready for shearing and to evaluate the quality of the wool, the women wearing their traditional clothing, long black woolen skirt, canvas on shoulders and braided hair.

to note that wool is not a highly processed material, as it is only cut from the sheep, cleaned, and spun, having the characteristics of being reusable, recyclable, and biodegradable. In addition, the animals do not need complex feeding, with good grazing management and supplementation at certain times of the year is enough for the sheep to produce wool [6], so it is of utmost importance to maintain the tradition of the production of handmade fabrics as a heritage, as it also helps to improve the economy of the different regions (i.e., Region Gualupita, Temoaya in the state of Mexico, Peña de Bernal in Queretaro, Region Tzotzil in Chiapas, etc.), besides being one of the factors that maintain the genetic diversity of sheep in Mexico [29].

4.2.1 Scenario 1

When comparing Mexico with wool-producing countries, it could be mentioned that, despite having a greater number of sheep, Mexico does not produce the same in wool; such as Uruguay, which in 2010 had 95% of heads of sheep that Mexico has and obtained a production 7.4 times greater than Mexico (**Table 3**). In the case of Australia, which is considered one of the main wool-producing countries, we can notice a big difference referring to the number of sheep, as well as wool production. On the one hand, Mexico only has 11.9% of sheep that Australia has and the production of wool in Mexico reaches 1.32% of the total of the Australian country. Another clear example is New Zealand, which in 2010 had a wool production 37.64 times more than Mexico with a sheep population four times more than Mexico [30].

4.2.2 Scenario 2

Mexico produces mainly coarse wool, since as mentioned, the crossing of the wool breeds with wool to have a greater production of meat, 95% of the national inventory is made up of native Criollo sheep, and only the remaining 5% belong to specialized breeds for wool or meat production, which has caused the quality of the wool to decrease considerably, however, this cannot be considered as a disadvantage since it is mentioned that thick wool (which is above 30 micron) is showing a growing trend worldwide, in greater demand than fine wool, which is being used in the manufacture of fabrics, carpets, blankets, among another uses [6, 12, 13], so it can be a solution so that the production of wool in Mexico does not disappear, since it's a developing market, some countries are not meeting their internal demands and Mexico could export this product instead of considering it a waste.

Another wool-producing country is Italy, which is not one of the main producers, however with its 6.3 million head of sheep, it produces 14,000 tons (from 1.2 to 1.3 kg of wool per sheep, depending on the breed), but only 5% of the production finds a commercial point of sale, so it presents a market very similar to that of Mexico, in addition to mainly producing coarse wool, if this wool is not transformed it represents a waste with additional cost [31]. So, Mexico could learn from the strategies that have been carried out in Italy and other countries, with the management and marketing of its wool, which it allows. Obtain added value and make it more attractive for producers to carry out the shearing in a more orderly manner and find a market that favors all sectors. Nowadays the Italian wool presents projects financed by private companies which try to support the local sheep producers, promoting the wool of autochthonous crosses, which is being destined to the production of handicrafts, handmade textiles, and the application of ecological constructions, based on the technological properties of local wool such as high insulating power, high water repellency, and high resistance to compression [32]. The financing of private organizations could be a solution for sheep Mexican wool farmers as well. However, governments are currently not supporting domestic producers and the outlook is very disappointing because 80% of the national sheep flock belongs to producers with low economic resources and low technological levels [13].

4.2.3 Scenario 3

Considering scenario 3, banks [33] discussed the evolution of the Australian lamb industry during the period of 1980–2003. The industry was negatively affected during the 80s and early 90s by the low prices of wool received by farmers and began a slow recovery in the late 90s. However, since 2000, the industry has experienced exceptional growth, where several sheep meat industry development programs helped in this recovery (e.g., Trim Lamb Campaign, Fresh Australian Range Lamb, and Lamplan). In this sense, the crossing was proposed to maintain the production of wool and meat, which was not considered in Mexico.

In Mexico, 95% of the consumption of sheep meat is as a typical food, in "Barbecue" (which consists of placing the meat in a hole in the ground, previously heated with firewood, and once the charcoal is bright red, the cuts of meat are introduced, placing a pot at the bottom, to contain the meat juice, and a grate so that it does not mix with the meat, this is covered with a few maguey stalks, and is left to cook for 12 hours, later it is uncovered and is ready for consumption) (**Figure 6**), which makes it difficult to have a quality standard of the produced carcass, since there is no distinction of cuts, and the only thing that is sought is the commercialization of animals weighing more than 40 kg [12, 13], regardless of breed, age, sex, body condition, or feeding system. After this period, Banks & Ross [34] showed that the genetic improvement in productivity and product quality increased by 4% per year at the end of the 1990s, generating a very competitive product (heavy lamb carcasses and lean, 18 kg–22 kg). This genetic success was associated with a positive combination of aggregate improvements throughout the sheep industry, which included better agricultural management, genetics, commercialization, and a consumer-centered industry. Continuous progress in the qualities of the carcass can be achieved by improving lean quality and increasing muscle [34], which in turn will result in more efficient production systems and higher meat yields. Gardner et al. [35] affirmed that the lamb industry can implement additional improvements through the strategic and intensive use of these genetic tools (i.e., artificial insemination or embryo transfer).

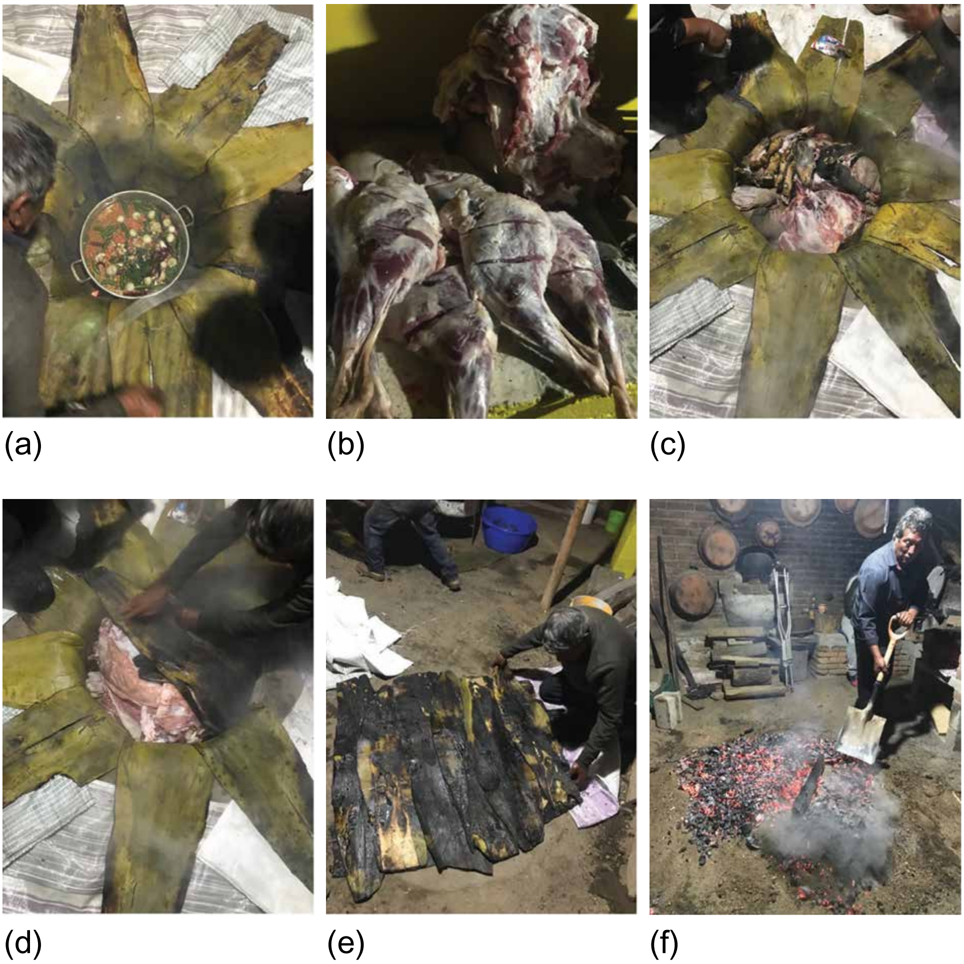

Figure 6.
Process of elaboration of "barbecue", as a typical regional dish of Mexico.

In a genetic improvement program, it is important to monitor the genetic progress obtained to verify if the improvement objectives are achieved, or if adjustments are necessary. One way to analyze the genetic gains obtained is to visualize the average reproduction values of the different characters evaluated by generation, as well as to study the direction and speed of change in each trait [36]. In general, it is considered that annual genetic progress of approximately 2% would be the maximum to achieve within a closed population that concentrates on the selection of a single characteristic [36], in our case and with the genetic diversity should generate strategies that lead to the selection of meat-wool breeds, without neglecting the autochthonous breeds that maintain the production of artisanal wool in certain regions of Mexico. Tzotzil women and men wear spun wool clothing for ceremonial or everyday use in different colors (deep black coats and skirts, white ponchos, brown blouses, and gray blankets), which is a clear example of the selection made by the shepherdesses and indigenous craftswomen [20].

Another clear example of these systems of meat-wool crosses has been in Uruguay where the genetic program of Texel (terminal crossbreeding) uses quantitative and genomic selection. From this program, some preliminary estimates for carcass quality traits (hot carcass weight, French rack, leg weights, intramuscular fat, and carcass fat indicator) resulted in moderate to high heritability (h2, ranging from 0.3 to 0.5) [36], without affecting wool production. When we look at the quality data of wool produced in Mexico and we want to compare it with other countries, but due to the lack of information it is not possible, but it can be said that the main wool production is from 27 to 40 micron. According to Perezgrovas and Castro [20], 36% of the income of indigenous communities in the southern region of Mexico (Oaxaca and Chiapas) comes from the realization of clothing and handicrafts. China in the present is one of the world's leading producers of wool, one of the reasons for the high production is the political and economic importance that ethnic minorities give to wool production since it is their main source of income [37]. Mexico not only has to give importance to wool production, wool quality, producers management training (as China does) but also must consider the climate and feed resources available in each region.

5. Conclusion

Wool production in Mexico continues to be deficient and therefore cannot meet domestic demand, having to resort to wool imports. It is necessary to consider that Mexico will not be able to completely cover the national demand since most of the commercial wool is of short and thick diameter, this is due to the great influence of meat breeds, such as Suffolk and Hampshire, which also have a great amount of black and brown fibers. The use of native resources of the region, such as the "Chiapas sheep breed" allows the development and maintenance of traditional ancestral culture, such as the Tzotzil, and the manufacture of handicrafts typical of each of the regions of Mexico; it is clear that Mexico will not improve its wool quality in the short term, however, the management of long-term programs through the inclusion of dual-purpose breeds, wool and meat can be a viable alternative for the development of the wool industry in Mexico, without affecting the production of sheep meat.

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Chapter 3

The Pastoralism in the Silesian Beskids (South Poland): In the Past and Today

Anna Salachna, Katarzyna Kobiela-Mendrek, Maria Kohut, Monika Rom and Jan Broda

Abstract

The Silesian Beskids (Poland), the westernmost part of the Carpathian Mountains is an area with long pastoral tradition. For centuries sheep grazed in clearings located among forested ridges have been an integral part of the mountain landscape and pastoral customs have become essential elements of regional cultural heritage. In the chapter, the history and the current state of pastoralism in the Silesian Beskids are presented. The specific pastoral system developed in the region, based on annual migration of flocks between summer highland and winter lowland pastures is described. Local breeds and specific regional sheep products are depicted. Furthermore, the importance of pastoralism for the environment, landscape and plant biodiversity is analysed and efforts to recover sheep grazing in the mountains after a period of a deep recession caused by social and economic transitions connected with the collapse of the communist system are presented. The approach to restoration of pastoralism is illustrated using a case study of a pastoral centre which combines traditional sheep grazing with cheese production, education and several activities to promote pastoral tradition.

Keywords: mountain areas, sheep farming, transhumance pastoralism, sustainable development

1. Introduction

The Silesian Beskids belong to the Carpathian Mountains, the second-longest mountain range in Europe. The system forms an arc throughout Central and Eastern Europe and stretches from the far eastern Czech Republic in the north-west, through Slovakia, Poland, Hungary, Ukraine, Romania to Serbia in the south. The range is roughly 1500 km long and covers the area of about 210 000 km^2.

The Silesian Beskids are located in the westernmost part of the Carpathians, in the border zone of the Czech Republic, Slovakia and Poland (**Figure 1**). The area borders with the Żywiec Basin in the east, the Żywiec Beskids in the south-east, the Little Beskids in the north-east and the Silesian Foothills in the north. The range covers an area of 561 km^2 and embraces two main ranges separated by the Vistula valley. The height of individual peaks ranges from 800 to 1250 m a.s.l. The highest peak, Skrzyczne, is 1257 m high [1].

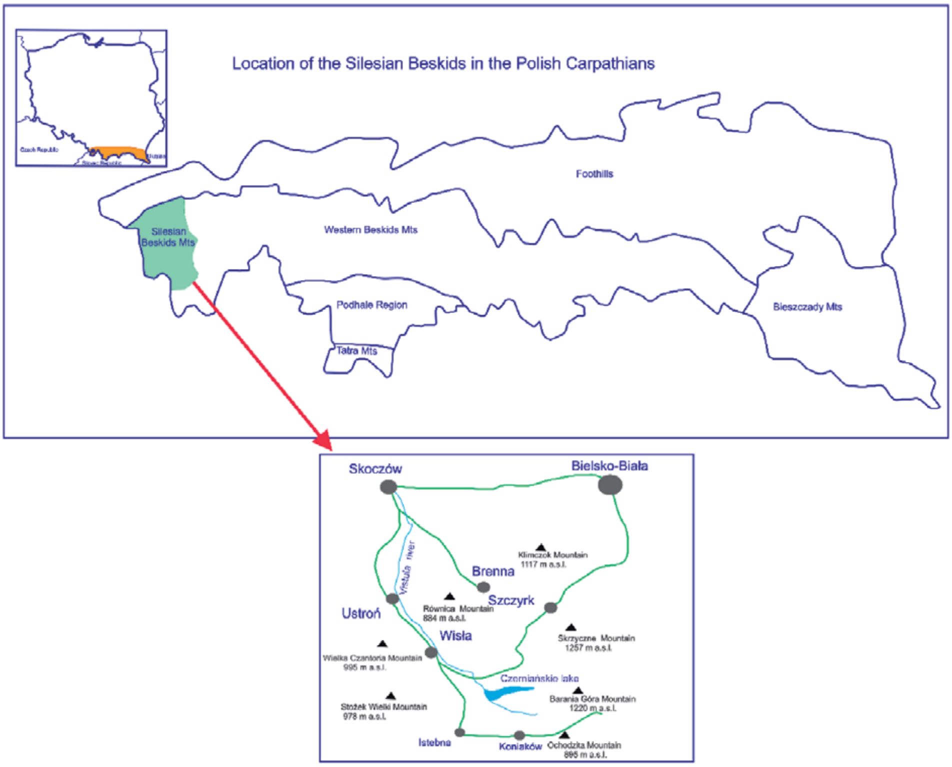

Figure 1.
Location of the Silesian Beskids in the Polish Carpathians

The Beskids are the mid-height mountains, characterised by extensive ridge forms with numerous flattening and deep valleys, with the longitudinal course (**Figure 2**). Their shapes result mainly from the geological structure which is dominated by the Carpathian flysch, i.e. alternately arranged layers of sandstone, conglomerates and slate.

The Silesian Beskids are located in the Carpathian climatic zone, in a temperate climate, shaped by polar and sea air masses. The climate is typical for medium-sized mountains and is characterised by low average air temperature, high precipitation and strong winds. The air temperature is determined by altitude, exposure and inclination of slopes. For the altitudes below 650 m, the average annual temperature

Figure 2.
Silesian Beskids landscape; (a) autumn; (b) winter.

Figure 3.
Typical mountain streams flowing down the peaks.

is 6–8°C [2]. As the altitude increases, the annual air temperature drops by 0.5 for every 100 m. Temperature on the southern slopes is 1°C higher than on the northern slopes. The average annual rainfall is above 1350 mm, which is one of the highest in Poland and higher compared to other parts of the Beskids [3]. The high precipitation results from the area protruding westwards and its greater exposure to rain-bearing winds from NW and SW directions. In the autumn, as the temperature drops, the precipitation changes into snowfall. The first snowfalls are recorded in October and can sometimes last until May. The number of days with snowfall varies greatly year to year and may amount up to even 200 days in the year. The snow cover remains for many months and in certain years it may be even 2 m thick. In many years snow cover stays for a long time in landslide depressions or densely forested places, which delays the growing season [4]. Climatic and physiographic conditions, i.e. high annual rainfall, heavy snowfall, significant inclination of the slopes and poor permeability of the flysch result in a formation of a dense river network (**Figure 3**). There are numerous springs including springs of the Vistula - the largest Polish river [5].

2. Pastoralism in the Silesian Beskids: history and present

Due to harsh climatic conditions, short vegetation period, steep slopes prone to water erosion, and lack of fertile agricultural land, the Beskids were uninhabited for a long time. The first settlers from the lowlands appeared in the region only in the 13th century [6]. The newcomers settled in the Beskid valleys, cultivated undemanding crops, mainly: rye, barley, flax, peas, and grazed cattle on lower-lying meadows.

About one-two centuries later, the Wallachian tribes appeared in the region. Their ethnic affiliation is not clear [7, 8]. In the Middle Ages “Wallachians” or “Vlachs” was the name used for pastoral people from the southern Balkans who led a semi-nomadic lifestyle. In the 13th century, the Wallachians started migration from the south, along the Carpathian Mountains. They continued until the 16th century, heading northwest up to the Silesian Beskids [9–12].

For several reasons, mainly economic and military, the Wallachian settlers could be attractive for local rulers. They were masters in mountain pastoralism and brought their pastoral know-how to new places [7]. Implementation of their ideas on sheep, goats and the specific breed of cattle grazing on mountain pastures and forests changed the social and economic reality in the vast area of the Carpathian Mountains [8, 12]. Sheep grazing in particular enriched the production profile and changed empty and less fertile mountain areas into lively pastoral settlements. The new activity created new tax collection opportunities for the land owners and generated higher income from the land. The Wallachians were not only experienced shepherds but also good artisans, highly skilled in carpentry, leatherwork and blacksmithing and were known to introduce and popularise innovative technique on rennet cheese manufacturing [7, 10, 11]. These innovations were easily transferred to and implemented by the local inhabitants. Together with innovations, the Wallachians passed on their own culture and pastoral lifestyle with different values and customs [13]. They also performed military-guarding function and served as police and border guards, controlling and securing strategic crossings through the mountains [10, 11].

The Wallachian transhumance involved the cyclical movement of herds between summer and winter pastures. This system was based on the natural difference in climate and vegetation between valley and mountain regions and assumed stabling and supplemental feeding practised only during the cold winter season [14, 15]. Animals were moved to highlands in spring to graze the lush forage in mountain clearings and in forests. In autumn the animals were brought down to permanent settlements into mountain villages.

The pastoral system implemented and spread by Wallachians was similar to other transhumance systems practiced around the world since animals were first domesticated, adopted and developed in different mountain areas in Europe [16]. The tradition of transhumance was common to all Mediterranean countries and for human and physical reasons was fully developed in the Iberian Peninsula [17]. According to recent archaeological studies conducted in Pyrenees in Spain, the system of altitudinal movements of sheep flocks was known already a few millennia before our era [18]. It was shown that sheep flocks with shepherds wandered from the pre-Pyrenean territories to the uplands to intermediate pastures placed between 1400 m and 1700 m a.s.l. After two months, the flocks were taken to higher grazing areas located above 2000 m a.s.l. On the way back in October the sheep were kept in intermediate pastures and after several weeks of grazing were taken to the lowland pastures.

In the Silesian Beskids, the traditional transhumance was modified and adopted to the local conditions [13, 19]. According to the local system, sheep were led into the mountains in the spring so that they would not use more fertile land in the village. In the early autumn, the animals were brought to the foothills and deeper valleys, where they were grazed in lowland fields. Then, the sheep were returned to the village, to their owners. In the early spring, after the lambs were born, the flocks were again grazed first in the valleys, in lowland pastures [12, 20].

The sheep were taken to summer pastures at the end of April, shortly after the snow had melted, just after the beginning of the vegetation season (**Figure 4a**) [12, 18–21]. In some regions the sheep were accompanied by whole families [12]. More frequently women and children stayed in the village in the permanent settlements, while the flock was put out to pastures by owners and male relatives [13]. In case of communal grazing, the sheep that belonged to various owners were brought together to form a bigger flock which was entrusted to hired shepherd called *baca* [12, 21]. The shepherd, assisted by a couple of helpers *(juhasi)* led the sheep to the pasture and was responsible for them during the whole summer. Joining sheep from

Figure 4.
Sheep grazing on mountain meadow; (a) summer pastures; (b) wooden enclosures.

different owners and forming the flock took place right before its leave and was connected with some rituals, which according to highlanders' beliefs ensured good health and protection for both people and animals they were entrusted with.

The shepherd and his helpers led the flock into grasslands located in the highest parts of the mountains, sometimes several kilometres away from the village. They lived seasonally in the pastures in huts made from easily available natural materials, wood and stones. During the entire season *baca* looked after the flock and coordinated all pastoral activities, including daily milking and production of cheese. For milking, shearing and overnight the sheep were kept in periodically shifted wooden portable enclosures (**Figure 4b**) [12, 20, 22].

The sheep and the people stayed in the mountains for 16–23 weeks [13, 20, 22]. At the end of September, the flocks returned to the village. For the next few weeks, the sheep were taken to lowland pastures in the foothills, lower located valleys or were grazed on fields and meadows located nearby the farm as long as possible. After the onset of frost and deep snow the animals were kept inside the barns and fed with hay. During the winter, in January and February, the new-born lambs were fed indoors with their mother's milk and hay, to help them grow quickly to be ready to leave with the flock to the summer pastures [12].

Settlements in the mountains and infertile or border areas were often established under Wallachian law *(IusValachicum)*, regardless of the ethnicity of the settlers. The law guaranteed the settlers free movement, they could leave the settlement without the permission of the landowner, carry weapon and pay taxes or tribute in the products of pastoralism: sheep, skin, wool, and cheese instead of serfdom [7, 10]. From the 16th century, most of the Silesian Beskids belonged to the Habsburg Empire. Initially, due to the lack of other ideas for using the mountainous grounds the Empire gladly supported the pastoral economy and made mountainous terrain available for grazing [12]. Sheep products were highly appreciated and guaranteed the highlanders a reasonable income. During prosperity, in order to expand the grazing area forests were cut and new mid-forest clearings were created [11, 19]. The prosperity lasted until 1853, when a law abolishing the peasants' right to use the manor's forests was established. Landowners began demanding high payments for the right to graze animals in the mountains, as they were destroying the forest stand which became a source of valuable raw materials and fuel for the growing industry. The fees for renting pastures increased [12] and further deforestation of the mountains was forbidden [11, 19, 22]. The community summer grazing became less profitable and gradually began to decline. This situation remained unchanged until the end of the Habsburg rule, till the end of the First World War. Attempts to regulate the rights of highlanders to mountain pastures and the rules for their use introduced after the war by government representatives of the newly created Polish state did not result in the revival of the pastoral economy [19]. Similarly, actions of communistic authorities after the Second World War failed too. In addition, new state borders drawn after the War separated pastoralists and their flocks from traditionally used pastures and fodder sources [22]. The situation worsened again drastically after the fall of communism in 1989 and the economic transition from the central to market economy. The economic changes associated with the drastic decline in demand for wool products caused sheep to disappear from the mountains [11].

After the collapse of the pastoral economy and a period of deep crisis, a regional project *Owca plus* aiming at renewing sheep grazing in the Silesian Beskids was implemented [23]. Oriented mainly towards cultural and environmental aspects, the project was financed by the local government of Silesia. Parallel to this project, other regional projects supporting sheep grazing in other parts of Carpathian Mountains were initiated. In addition to regional projects, a national program for the protection of genetic resources of local breeds was launched. The implementation of the projects coincided with the accession of Poland to the European Union and was in line with the EU priorities regarding multifunctional agriculture, related to the Common Agricultural Policy (CAP) as well as to the idea of sustainable development [24, 25]. In the same time EU funds were launched to support sheep farming. As a result of all projects the interest in pastoral economy in Poland slightly increased and in the 2018 the sheep population reached 270 000 [26]. In the same time a slow recovery of sheep grazing in mountain pastures was observed.

3. Mountain sheep and their products

3.1 Sheep breeds

Zackel sheep, brought to Poland from the southern Europe by the Wallachian tribes, are raised in the Beskid Mountains until today [27]. Zackel is a large group of sheep, which includes several local breeds. The group is widely spread in Central-Eastern and Southern-Europe, especially in the Balkans and Carpathian Mountains [28]. It is an undemanding primitive breed and is characterised by high resistance to diseases and harsh climatic conditions. The sheep are strong and well adapted to long treks and steep, hardly-accessible mountainous pastures. Moreover, they are distinguished by their longevity, strong mothering and herding instinct. The animals are rather small in size, possess a bare head and slight convex profile with a long and thin tail (**Figure 5a**). Thanks to their long neck and narrow mouths the sheep can eat scant vegetation in the pastures. Rams have long spiral horns, while

(a) (b)

Figure 5.
Mountain sheep: (a) Zackel Sheep; (b) Polish Mountain Sheep.

ewes can be either horned or polled. The height of the adult sheep is ca. 60 cm at the withers and their weight can reach the maximum of 30–35 and 45–60 kg for ewes and rams, respectively.

The sheep are covered by the open wool coat of considerable density, with long flocks falling on both sides of the trunk. The typical colour of the fleece is white. Dark spots may occasionally appear around the eyes, at the mouth and ear ends. Three types of fleece fibres form under, intermediate and guard fractions. The thick guard hair of the outer coat provide physical protection against snow, prolonged rain and injuries, while the soft undercoat ensures the necessary thermal insulation [29]. The wool collected from different animals differs considerably in terms of fibre thickness, weight ratio of fractions, and content of coarse fibres [30].

In many countries, the usefulness of Zackel sheep was repeatedly improved through cross-breeding with other more noble breeds [31, 32]. In the late 19th and the early 20th centuries, several attempts of improving Polish Zackel were undertaken. For a long time the results of the cross-breeding were unsatisfactory due to decreased immunity, reduced fertility and lower wool quality. The considerable refinement of the breed was achieved only after the Second World War by the cross-breeding of Zackel ewes with Friesian rams and Transylvanian Zackels. In this way a new breed: Polish Mountain Sheep was produced (**Figure 5b**).

The Polish Mountain Sheep maintained Zackel's adaptability to steep pastures and harsh climatic conditions as well their low feed requirements, longevity, high resistance to diseases and adjustment to extensive production systems. Through the use of Friesian rams the characteristics and yield of wool were enhanced. The goat type and numerous core hair observed in Zackel sheep were displaced and the fibres of the inner coat were lengthened. Simultaneously, the wool became thinner and achieved better physical parameters [33]. Thanks to Transylvanian Zackels, certain body conformation traits were improved. Crossbreeding also led to a significant increase in body weight and milk yield. Compared to the Zackel sheep, the body-weight for adult sheep was approximately 10 kg greater and reached 60–70 kg for rams and 45–50 kg for ewes.

The Polish Mountain Sheep is distinguished by light and harmoniously built trunk, supported by rather thin and strong limbs and a cut, narrow rump. The head is light, with a straight profile, usually horned in rams, less frequently in ewes. The sheep are covered with an open coat with a characteristic dorsal section. The coat covers the sheep's belly, limbs at least to the ankles and head to the line of the eyes. For the majority of the sheep, the coat is white. Occasionally, brown or black colour variations are encountered. The fleece forms double coat consisting of a soft, insulating undercoat coupled with a hard outer coat. Additionally, the fleece has a significant amount of a thick and brittle kemp.

3.2 Sheep products

Sheep raised in the Beskids, both Zackel and Polish Mountain Sheep belong to versatile breeds reared for meat, wool and milk. For years, all sheep products were effectively used and provided existence for highlanders' families.

Sheep meat, both lamb and mutton, was an important element of the highlanders' diet, eaten mainly during festive periods and important family events. In other parts of Poland, where pork and beef were more popular, mutton was underestimated. Nevertheless, mountain sheep grazed on natural pastures rich in herbs, unfertilised, with diverse botanical composition of the sward produced meat with less fat, containing biologically active substances and with the preferred profile of fatty acids [34]. Because of its pro-health properties, despite the lack of national tradition in mutton consumption and certain prejudices stemming from the communist past, sheep meat is more and more appreciated. Domestic and foreign consumers show growing, special interest in meat obtained from lambs aged less than 60 days, for which the weight of carcases ranges from 4 to 8 kg. These lambs are fed only with mother's milk and hay, which results in minimal fat content in the meat. The meat is light pink and has a soft, elastic and pliable texture. It is delicate, succulent, its aroma similar to venison.

The wool is obtained by shearing, which is usually performed twice a year in the summer, outside on pastures and in the winter, before littering, in the fold. For the Zackel sheep, the weight of grease wool ranges from 1.5 to 2 kg. For Polish Mountain Sheep the greasy fleece is heavier and may reach 2.5 kg for one shearing. Wool obtained from both breeds is coarse and not uniform, its properties are much worse in comparison to fine merino wool used for the production of luxury apparel fabrics. Despite poor quality and relatively low price, for many years wool was the most precious sheep product generating the highest income for the sheep owners. During prosperity, it was processed under industrial conditions and used for manufacturing blankets, carpets and other carded products. A significant amount of wool in the form of loose fibres was used as filling of quilts and sleeping bags. Wool was also used by the handicraft sector and often processed using old, traditional methods passed on from one generation to the next. In this way, felt, and cloth used for the production of different elements of traditional highlander dress: pants, hats and gowns were obtained. Additionally, wool was widely used to produce hand spun yarns used to knit traditional highlander sweaters and socks. In the last decades, together with economic transitions and the appearance of competing products made from synthetic fibres the demand for wool products has rapidly decreased and the interest in mountain wool both from the textile industry and the craft sector has dropped heavily. Consequently, mountain wool has drastically lost its economic value and the costs of sheep shearing have outweighed the price of wool. Several attempts to use wool in an unconventional way as fertilisers [35–38] and soil reinforcement [39] or for production of thermal and acoustic insulating materials [40–42] and geotextiles [43] have not, so far, gained greater importance. Therefore, wool is now treated as a troublesome waste of sheep breeding, which is buried out on the fields, stored without being scoured or deposed in local, not always legal, landfills.

At present, sheep product which has the highest economic importance is sheep milk. Sheep are milked by hand, twice a day during grazing on the mountain pastures. The milking begins after weaning the lambs and lasts from May until October, around 150 days per year. An ewe produces about 70 litres of milk yearly. It has high nutritional value and contains 15–20% of solids, 4.5–9% of fat, and 4.5–7% of protein. Moreover, the milk is rich in water-soluble vitamins, has a beneficial fatty acid profile and is more calorific than cows' milk [44–47]. It is used for the production of traditional local cheeses, the most known are: *bundz, bryndza* and *oscypek*, registered as regional products under the EU regulations.

Bundz is a cottage cheese with mild and gentle flavour, which is the first product made of clotted milk. The cheese is white or white with a shade of aquamarine (**Figure 6a**). Fresh *bundz* is sweet taste due to natural lactose in milk. Lightly salted *and* left for several days becomes sour and mature and produces characteristic holes well visible in its cross-section.

Crushed, grounded and salted mature *bundz* is used to make *bryndza*. *Bryndza* is creamy or semi-spreadable, of white to grey in appearance and sharp and salty taste. *Oscypek* is a hard smoked cheese made from salted sheep's milk with an acceptable addition of cows' milk of Polish Red breed (max. 40%). The cheese has a characteristic spindle-like shape, weights between 600 and 800 g and measures between 17 and 23 cm (**Figure 6b**). It has a unique spicy, slightly salty taste and glossy, yellow to light brown colour.

(a) (b)

Figure 6.
Traditional sheep's cheese made in the Silesian Beskids: (a) bundz; (b) oscypek.

All these cheeses are made using traditional methods passed on from generation to generation. First, raw milk is poured into a container, slightly heated and mixed with a rennet. During heating and mixing milk proteins coagulate forming the curd which then is brewed for a few minutes at a temperature of about 70°C. When making *bundz* the curd is strained and pressed on the canvas in the form of big lumps. In a further step, the lumps are hung on the walls to dry and set aside for up to two weeks to mature. To produce *oscypek* the curd must be kneaded in the bucket and torn into portions. The cheese blocks are repeatedly kneaded and brewed in hot water. During kneading the cheese is formed into a characteristic double-sided cone shape with a cylindrical central part decorated with traditional patterns. The spindle-shaped cheese is soaked for a night in a brine-filled barrel, dried and smoked for a few days above a fire.

4. Vegetation of the Silesian Beskids

In connection with large differences in altitude above sea level and the related changes in climatic conditions three altitudinal vegetation zone are distinguished in the Silesian Beskids.

The lowest vegetation zone up to 550 m a.s.l. is the foothills. At present, the zone belongs to the most transformed areas of the Silesian Beskids, which is heavily populated and includes a large deforested urban and rural area. There are many buildings, an extensive network of roads and many crop fields, which spread to the edges of the forest on mountain ridges. Only 26% of the zone is covered with forests. They form small patches of deciduous and mixed woods consisting of oak *Quercus robur*, lime *Tilia cordata* and hornbeam *Carpinus betulus*. The forests occur mainly along watercourses and on hills not used for agriculture.

The lower and upper mountain forest zones at altitudes between 550 and 1250 m a.s.l. are heavily forested. Trees cover up to 60% of the area and currently consist mostly of Norway spruce *Picea abies* monocultures (70%). The spruce stands were formed at the expense of lower montane primaeval forest, composed of spruce *Picea abies*, beech *Fagus sylvatica* and fir *Abies alba*. Currently, these natural forests cover less than 1% of the area and are protected as nature reserves [47].

The composition of the forest stands changed in the second half of the 19th century as a consequence of high demand for wood. In that time, to increase wood yield the intentional reforestation with the spruce, as the most cost-effective species, was performed. Spruce wood was considered universal and was used in large volumes for the construction of the expanded Carpathian railway network and other industrial applications [48]. Introduction of spruce on a large scale caused the shortage of seeds which had to be imported regardless of their provenance. Due to the lack of local seeds, allochthonous seeds from the surroundings of Innsbruck and Steiermark, other parts of the Austrian Habsburg empire were used [49]. As a result of monocultural reforestation and planting the allochthonous seeds, the forests have become more susceptible to diseases and pest attacks. The consequences have been well visible in recent years, since the beginning of 21th century, as gradual drying-off and decay of trees caused by an outbreak of the spruce bark beetle *Ips typographus* has been observed [50] (**Figure 7**).

Apart from the monocultures of spruce stands in the lower forest zone of the Silesian Beskids there are patches of deciduous forests. The most common communities are fertile Carpathian beech wood *Dentario glandulosae – Fagetum* and acidophilic montane beech wood *Luzulo nemorosae – Fagetum* (**Figure 8**).

In addition to extensive wooded areas on mountain ridges, mid-forest clearings of various sizes occur. The clearings are extremely valuable habitats and play an important role as refugia of biodiversity. The most valuable meadow and pasture plant communities include *Arrhenatheretum elatioris, Gladiolo-Agrostietum capillaris,*

Figure 7.
Infected forest in Skrzyczne region (the highest peak of the Silesian Beskids).

Figure 8.
Beech forest in the Silesian Beskids.

Cirsietum rivularis, Hieracio-Nardetum (**Figure 9** a) and *Carlino-Dianthetum deltoidis* [51]. These plant assiociations are phytosociological identifiers of natural habitats demanding protections as Natura 2000 areas [52]. Moreover, the clearings are the sites with many rare and protected plant species such as *Carlina acaulis* (**Figure 9b**), *Colchicum autumnale, Dactylorhiza majalis, Epipactis palustris, Gentiana asclepiadea, Gladiolus imbricatus, Gymnadenia conopsea, Platanthera bifolia* [53].

Since the 16th century the clearings had been used as summer pastures, mainly for sheep. In the following two centuries, in the period of quick development of mountain grazing, parts of the forest stands were cut down. As a result, the existing clearings were enlarged and numerous new clearings were established. In the next centuries until the mid-20th century, when the pastoral activity declined and intentional reforestation was performed, the area of mountain clearings slightly decreased. The next rapid decrease of the clearing surface took place at the end of the 20th century, in the period of social and economic transitions connected with the almost complete cessation of sheep grazing. In this time as a result of ecological succession, the clearings began to overgrow with shrubs and trees (**Figure 10**) [54, 55].

Figure 9.
The valuable plant communities and species on mountain clearings in the Silesian Beskids Mts: (a) priority habitat of Hieracio-Nardetum*; (b) protected species* Carlina acaulis.

Figure 10.
Mountain clearing overgrown with shrubs and trees.

The process of overgrowing clearly shows the great importance of sheep grazing for the maintenance of mountain clearings and protection of their precious plant communities. It is known that sheep eat plants selectively, choosing species with soft leaves and avoiding those with a xeromorphic structure. As a result, sheep inhibit the growth of tall grasses such *as Lolium perenne, Phleum pratense, Festuca pratensis* and others, prevent the expansion of cosmopolitan weeds and the succession of shrubs and trees. Trampling of pastures by sheep improves the humidity and air content in the top layers of the soil. This creates favourable conditions for the development of phytophilous and thermophilic meadow and grassland species, which are very valuable elements of biodiversity [56]. Sheep may carry seeds of even 85 plant species, attached to the wool around their neck and breast [57]. By moving around pastures sheep spread seeds of xerothermic species and contribute to increasing the species diversity.

It was clear that restoration of pastoral activity in the Silesian Beskids would be a great opportunity to preserve and protect mountain clearings, their precious plant communities and biodiversity as well their unique landscape values.

5. Case study

An example of actions aiming at restoration of pastoralism in the Silesian Beskids is the activity of the Centre of Regional Produce. The centre was founded by Maria and Piotr Kohut and is located in the mountain village of Koniakow, Istebna municipality, in the eastern part of the Silesian Beskids, in the border zone between Poland, Czech Republic and Slovakia. The centre was opened in 2003. Since then, it has been involved in several activities including sheep grazing, production of cheese, sale of sheep products, education and promotion of the pastoral culture. The centre grazes a big, as for Polish conditions, flock which counts over 1000 sheep, the vast majority of it owned by Kohut family. For several years, the size of the flock has been systematically growing from 500 in 2010 to 1000 in 2020. Grazing is carried out traditionally on a nearby, non-forested Ochodzita mountain, at 895 m a.s.l., famous for its beautiful panorama and vast resources of green forage (**Figure 11**).

The specification of sheep grazing carried out by the centre is presented in **Table 1**.

The sheep milk is used to produce traditional cheeses which are manufactured in a traditional way in the village. During one season from April until September,

Figure 11.
Panoramic view from the Ochodzita mountain; (a) to the south; (b) to the north.

Grazing	
Localisation of pastures	Mountains: Ochodzita, Barania Góra, Magurka Radziechowska Villages: Koniaków, Kamesznica
Ownership of pastures	Private, about 300 land owners
Shepherds *(baca)*	High qualified with very large professional experience, master exam in the profession of *Baca*
Helpers *(juhas)*	8 persons - Hutsul highlanders from Ukraine experienced in sheep grazing
Shepherd dogs	Tatra Shepherd Dog, Bernese Mountain Dog
Sheep number	Total: 900–1200 sheep divided into two flocks: 1. milk ewes; 2. ewes with lambs
Ownership of sheep	500–600 sheep belong to Kohut family; the remaining to 25 owners
Sheep breed	Mainly white Polish Mountain Sheep with small number of colour variety; small number of Zackel Sheep and Romanian Tsurkana Sheep
Pastures	Natural mountain vegetation not fertilised chemically
Watering	Water drawn from natural sources
Overnight keep	The sheep spend nights in pastures, in wooden portable enclosures
Grazing time	From late April/early May until late October
Milking	
Milkyield	Daily average yield 0.7 l milk per ewe
Frequency	Twice a Day
Number of workers	6–7 persons
Milk processing	Milk transported to the Centre for processing
Products	Different kind of sheep cheeses: *oscypek, redykołka, bundz, bryndza*
Lambing	
Time	Winter–spring period: January, February
Fertility	Reproductive performance: 1–2 per ewe
Shearing	
Time	Sheep sheared twice a year, in summer and winter
Greasy fleece weight	1.5–2 kg of greasy wool

Table 1.
Specification of grazing carried out by the Centre of Regional Produce in Koniakow.

approximately 50 000 litres of milk are obtained. One portion of the milk is used for the production of 100% sheep cheese. The annual production of this cheese is approximately 5 000 kg, which at the retail price per kilogramme of 10 Euro gives the production value over 50 000 Euro. The second portion of milk is mixed with cow milk and is applied for manufacturing a smoked cow-sheep cheese. The production of mixed cheese reaches yearly 3 500 kg and its value approaches 60 000 Euro. In 2008, the smoked cheese *oscypek* received the EU certificate for the protected regional products (Protected Designation of Origin). Other cheese, smoked *bryndza,* received the prestigious award in the culinary competition for the best Polish regional products.

The centre sells sheep cheese, mutton and other regional products in its shop. The main clients are tourists, local food sellers, as well as restaurant and hotel representatives. The average annual value of goods sold in 2017–2018 amounted to 250 000 Euro of which approximately 70% originated from the sale of sheep's cheese.

As a member of the National Network of Educational Farms, the Centre offers lectures and workshops which popularise the pastoral culture among the local community and tourists (**Figure 12**). The educational classes present traditional cheese making methods and wool spinning techniques. The classes are very popular among schoolchildren, students and adults, so the number of participants in the last five years has reached 10 000.

In addition to educational activity, the Centre takes numerous efforts to sustain the pastoral tradition and cultural heritage in the local community and promote them in the Polish society. Each year, the departure of sheep to pastures and their return to the village is connected with several rituals, which became important social events attracting a growing number of tourists (**Figure 13**). Sheep grazing in the mountain pastures make the mountain landscape more attractive and

Figure 12.
Social activity of the Centre in Koniakow; (a) cheese market; (b) cheese production workshops.

Figure 13.
Ceremonial leave of the flock to the summer pasture.

extensively promote the Silesian Beskids region. Through implementation of the Polish-Slovak interregional project and establishing the Transhumance Pastoralism foundation, the promotional activity of the Centre extended beyond the Polish border. In 2013, to co-memorise Wallachian migration through the Carpathians the foundation organised a sheep hike. As part of the project, Piotr Kohut and 300 sheep travelled 1200 km from Romania through Ukraine to Poland. The hike was accompanied with several social events, which significantly recalled and promoted the pastoral tradition on the international level.

Through its rich activity, the centre provides several work places. In addition to the owners, it employs shepherd helpers for sheep grazing and cheese production, seasonal workers for hay harvesting, sales workers and instructors for educational workshops. The shepherd helpers are usually recruited from Hutsul highlanders from Ukraine, while others come from the local community. The total employment in the high season reaches 15 people.

6. Conclusion

The beginning of sheep grazing in the Silesian Beskids dates back to the 16th century. The implementation of the pastoral economy transformed the social and economic reality of the mountain villages. The development of the specific pastoral system based on annual migration of flocks between summer highland and winter lowland pastures enabled rational use of natural local resources. Sheep have transformed hitherto inaccessible mountain areas and made human life possible.

For the next two centuries, the pastoral economy was developed, experiencing a relatively long period of prosperity. Sheep were the main source of livelihood and the basis of the economic existence for many highlander families. All sheep products: wool, milk, meat and skin, were greatly appreciated, possessed high economic value and generated reasonable income. Pastoral activity greatly influenced the landscape and contributed to the establishment of new mid-forest clearings with rich plant communities. Shepherding had also impact on the local architecture with wooden huts used by the shepherds in mountain pastures becoming the permanent landscape element. The pastoral economy drove the development of methods for manufacturing sheep's cheese and processing the wool. For years, the traditional methods were applied and faithfully passed on to the next generations. In connection with the pastoral activity, several customs and rituals were established. All components of the pastoral activity became important elements of the cultural heritage of the region.

From the mid-19th century sheep grazing in the Silesian Beskids was becoming less profitable and the importance of the pastoral economy and its influence on social life of mountain communities was systematically decreasing. At the end of 20th century, after the collapse of the communist system, sheep almost disappeared from the mountains. The restoration of the pastoral economy required decisive action and implementation of several regional and national projects focused on preserving the landscape values, preventing mountain clearings from overgrowing with shrubs and trees, protecting the precious habitats and protecting the cultural heritage of the region.

After several years of implementing these programs, the first positive impacts are visible. The projects became tools to protect, restore and promote sustainable use of the terrestrial mountain ecosystems, stop and reverse land degradation and halt biodiversity loss. The population of sheep grazed on mountain clearings has increased considerably. The existing flocks have been enlarged and some new flocks grazed in earlier abandoned pastures have been formed. Simultaneously, the projects showed that sheep grazing is not just a matter of enthusiasm or a hobby, but rather the natural activity within the region, which can generate economic income. Through various educational and promotional activities of foundations and pastoral centres, the pastoral traditions have been popularised. The activities attract tourists, who are more and more interested in tasty regional sheep products and the cultivation of pastoral tradition.

Based on the results these projects, one can conclude that restoration of the pastoral economy in the Silesian Beskids is not only possible but absolutely necessary. The restoration of pastoral economy fits several European Sustainable Development Goals (SDG) and brings many economic and social benefits. The current activities need to be continued and supported with new initiatives including appropriate legal regulations, subsidies and further projects.

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Conflict of interest

The authors declare no conflict of interest.

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Chapter 4

Assessment of Sustainability of Dairy Sheep Farms in Castilla y León (Spain) Based on the MESMIS Method

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Abstract

A livestock system is a productive unit, but in addition, if it pursues an optimal use of natural resources, it can increase overall sustainability. In order to evaluate the fulfillment of this objective, it is necessary to carry out a diagnosis of the system to describe and evaluate its degree of sustainability. One methodological option for this diagnosis is the construction of sustainability indicators. The MESMIS method is a methodological tool that analyses the interrelations between the results of the environmental, social and economic dimensions through a battery of indicators. The aim of this work is to assess the sustainability, using the MESMIS methodology, of different management systems of a sample of dairy sheep farms in Castilla y León (Spain). In general, the semi-extensive group obtained the highest overall score (8.40), and the intensive group achieved the highest volume of productivity. In conclusion, semi-extensive systems were more sustainable than intensive or semi-intensive systems in all attributes, especially those related to stability, adaptability and equity.

Keywords: sustainability, MESMIS, diagnosis, dairy sheep farms, livestock

1. Introduction

Sustainable development was proposed as a response to the growing awareness of determining relationships among social and economic development, global, regional, local and rural environments, and population growth with its continuous urban concentration [1]. Despite the high complexity associated with sustainable development, efforts to achieve it have become common practice at all levels of public policy, from governmental laws [2] to regional and private decision making [3] because of the potential consequences of not achieving it; i.e., that the environment's capacity to ensure a certain welfare level would actually be disrupted [4] with serious effects on human societies [5]. Achieving sustainable development requires a substantial, complex and persistent effort, yet addressing the widely acknowledged necessity of how best to measure it is the first step.

Identifying sustainable development indicators at the microeconomic level raises the question of which information is relevant because sustainable development involves three interconnected components that must be addressed per productive unit; viz., environment, equity, and futurity (the ability to manage resources in a long-term perspective and with appropriate respect for future generations). The interdependence can be reflected by several economic, social, and environmental variables that are interconnected and to the additional dimension of time, which emphasizes the long-term perspective [6].

An assessment of a system that describes and quantifies sustainability requires identifying the limitations that affect its operation, the causes behind these limitations, and identifying the potentialities. Thus, proposals can be made to improve farms in accordance with the producer's real requirements [7].

Evaluating sustainability is not an easy task; it is a complex task to integrate all edges of the concept to reach a single conclusion on the ecological, social, and economic characteristics and implications of a given system. However, there is also a vital need to identify indicators to assess the relative degree of sustainability of proven production systems, especially those in the rural sector [8], which are needed to develop policies that promote respectful practices that are consistent with sustainability.

Among the efforts to make the sustainability of complex production systems operational based on indexes, indicators and frameworks [9], the Framework for the Assessment of Natural Resource Management Systems incorporating Sustainability Indicators (MESMIS) [7] has played a leading role in sustainability assessments because it was one of the first to use a multidimensional approach in addressing the sustainability of agricultural production systems.

This study assessed the sustainability of 17 dairy sheep farms in Castilla y León (Spain), clustered into three management styles; i.e., semi-intensive, intensive, or semi-extensive, based on the MESMIS. To evaluate the results from that method, the statistical analyses were used to assess the indicators of each attribute and the management system.

2. Methods

MESMIS is a method of analysis that helps to quantify sustainability through a comprehensive analysis of management systems. It is based on the interrelationships between environmental, social, and economic processes [10], and aims to maintain or improve productivity, reduce risks and uncertainty, protect resources and prevent soil, water and biodiversity degradation, without diminishing the economic viability of the system [11]. MESMIS includes the local factor as a fundamental diagnostic component, identifies endogenous responses, which makes it a method that is permanently under construction [7]. The assessment must be comparative and cyclical, and it begins characterizing the system, the integration of indicators, and the formulation of conclusions and recommendations for improving the management system.

MESMIS requires the following phases [7]:

1. Definition and description of the farms assessed.

2. Characterization of the management systems.

3. Selection of indicators and development of attributes.

4. Tool's global assessment and sustainability measurement.

5. Proposal of corrective or improvement measures.

This work compiles a set of contributions generated by the Castilla y León team that was involved in the R + D + i research project of the National Institute of Agricultural Research "Incidence on the quality of products and the environment of different livestock farming systems with small ruminants of dairy aptitude. Use of economic, social and environmental indicators and final typification of systems". The project was within the Sub-program of fundamental research projects oriented towards agricultural resources and technologies in coordination with the Autonomous Regions ["of Spain"]. The aim of the project was to evaluate agricultural and livestock sustainability based on the NAIA indicator system in four Spanish Autonomous Communities; i.e., Castilla y León, Navarra, País Vasco, and Andalucía. The project modified the original NAIA method, which is typically applied to livestock farms, to adapt it to the analysis and diagnosis of small ruminant farms (sheep and goat). The final NAIA method involves the calculation of 133 variables, which are assigned to one of 20 indicators that are integrated into three dimensions, see **Table 1**. All the information about the original tool and its indicators is available at https://neiker.eus/en/patents-and-varieties/.

The distribution of indicators in the NAIA method is a classical version of structural analysis that is divided into functional categories; viz., economic, social and environmental. The method was developed as a proposal for improving farms and a solution manual for institutions. Therefore, it is reasonable that it replicates that traditional scheme and focuses attention on those aspects that depend directly on livestock management and administration. The variables and indicators used in the project were adapted and organized for the construction of the MESMIS attributes.

1. Productivity: ability of the agro-ecosystem to provide the required level of goods and services. It is the value of the attribute in a given period.

	Economic	**Social**	**Environmental**
Indicators	Profitability (8)	Employment Characteristics (7)	Livestock/Surface balance (5)
	Autonomy (6)	Employment creation (4)	UAA[a] used and management (7)
	Diversification and risk (6)	Life quality (5)	Soil nutrients balance (8)
	Cost structure (4)	Employment quality (17)	Effluents management (4)
	Stability (3)	Animal Welfare (9)	Natural resources and diversity (7)
		Traditional systems and landscapes (8)	Energy (7)
		Product quality and proximity (9)	Emissions (4)
		Gender (5)	

[a]Utilized agricultural area (UAA), is the total area taken up by arable land, permanent grassland, permanent crops and kitchen gardens used by the holding, regardless of the type of tenure or of whether it is used as a part of common land. (number of variables involved in each of the indicators).

Table 1.
NAIA method: Dimensions, indicators, and variables.

2. Stability: property of the system that is in a state of dynamic equilibrium.

3. Adaptability: capacity to find new balances that maintain the productive potential "vis à vis" external changes. This attribute includes aspects related to the diversification of activities or technologies processes of social organization, training of human resources, and learning.

4. Resilience: capacity of the system to return to an equilibrium or to maintain its productive potential after suffering severe disturbances (e.g., catastrophic events, hurricanes).

5. Reliability: capacity of the system to maintain productivity or benefits near balance levels when facing normal environmental disturbances.

6. Autonomy: capacity of the system to regulate its interactions with the outside.

7. Equity: ability of the system to fairly distribute the benefits and costs of natural resource management intra- and inter-generationally.

The sustainability assessment is performed and is valid for the following, only:

a. Specific management systems in a given location and within a certain social and political context.

b. A previously defined spatial scale (plot, production unit, community or watershed).

c. A priori defined temporal scale.

The analyses presented in this paper met all of the conditions required for the results to be consistent. The selection of the indicators needed for the construction of the attributes was based on the NAIA method. **Table 2** shows the relationships between the NAIA indicators and the MESMIS attributes which make the MESMIS more concrete.

In the NAIA and MESMIS adaptation, two attributes have been merged into other categories as follows:

- Resilience has been merged with Adaptability based on the understanding that the possibility of finding a balance again includes the development of a scenario that is consistent with a previous safe and reliable scenario.

- Reliability has been merged with Stability and Productivity because an adequate combination of the two provides a strong economic balance "vis à vis" disturbances in the system.

Thus, the proposed MESMIS scheme is organized around the following five attributes: Productivity, Stability, Adaptability, Autonomy, and Equity (see **Table 6** and **Table 7** (bis) of the appendice).

The graphical representations of the results were radial graphs (amoebas). The optimal value for each indicator is the maximum value in the NAIA Tool tables. The maximum and minimum values are the absolute values of the Castilla y León's sample (17 farms). To create each graph, the origin of the data was transformed into a range from 0 to 10. Thus, the system that is closest to the optimum for each

	Overall average	Group average		Overall average	Group average
Management system results			Environmental results		
Sheep	799	890	Cost/ha x 10 (MJ)	164.160	319.040
M^2 Built	2412	3013	Net Cost x 1000 (MJ)	6.665.000	8.236.000
M^2 /sheep	3.15	3.16	CO_2/ha (Kg Eq CO2)	17.223	39.123
AWU	3.66	4	Milk quality		
Family AWU	2.33	2	Protein (%)	5.6	5.41
UAA (ha)	68.66	32	Fat (%)	7	6.92
Own UAA (ha)	17.33	14	Omega 6 / Omega 3	4.8	5.98
External UAA (ha)	51.66	18	CLA	0.66	0.61
UAA /sheep (ha/ sheep)	0.08	0.03	Alfa-tocopherol	102.42	70.57
Communal Ha	308.33	0	Retinol	63.58	58.07
Economic results			Somatic cells	1,042.84	985.34
Income	240.43	298.56	Life and work quality		
Capital	378.07	437	Life quality	3.12	2.8
Direct expenses	129.94	201.14	Work quality	3	2.2
Indirect expenses	132.1	100.29	AWU: Agrarian Work Unit		
Gross margin	149.73	116.5	UAA: Utilized agricultural area		
Net margin	17.63	16.21			

Annual work unit (AWU) is the full-time equivalent employment, i.e. the total hours worked divided by the average annual hours worked in full-time jobs in the country. One annual work unit corresponds to the work performed by one person who is occupied on an agricultural holding on a full-time basis.
Cost/ha x 10 (MJ) are the direct and indirect energy costs per hectare expressed in megajoules, calculated according to the formulas of [12].
Net Cost x 1000 (MJ) are the direct and indirect energy costs minus the energy inputs derived from the production of lambs and milk expressed in megajoules, calculated according to the formulae of [12].
CO2/ha (Kg CO2 Eq) are the greenhouse gas emissions expressed in kilograms of CO2 equivalent and calculated according to the formulae of [12].

Table 2.
Characteristics of intensive farms.

indicator can be identified. For negative values (i.e., Net Margin), We used mathematical distance to the optimum, therefore, the segment represents the distance to the optimum of either a positive or a negative value.

1. To identify the strengths and weaknesses of the management systems and to provide suggestions for improving their sustainability, the information on the attributes was evaluated globally and by the management system.

2. Similarities in the performance of the three types of management (semi-intensive, intensive, and semi-extensive) were evaluated based on the indicators of each of the attributes. The method involved following two tests: a) Shapiro-Wilks normality test (normality test for a sample size <50), which establishes the null hypothesis that a sample came from a normally distributed

population, and b) the t-Student test for normal samples and the Kruskal-Wallis (H) non-parametric test for non-normal samples. The results will indicate whether the three types of management for each of the indicators of the attributes has similar performances. The null hypothesis was that the three groups analyzed did not show differential behavior in a given indicator (significance level 0.05).

3. Sample description and farm classification and characterization

Farms were selected based on the knowledge of technicians who worked in this region and the aim was to obtain a sample that was representative of the dairy sheep systems in Castilla y León, which is a landlocked region in the northwestern of the Iberian Peninsula (**Figure 1**). It has an area of 94,225 km2 (12% of Spain) and is the largest Spanish region. In 2019, there were 2,689,415 sheep (17.4% of the national total) which made it the Community that had the highest concentration of sheep in Spain.

In that project, an initial classification of management systems was based on four types of farms based on seven discriminating variables, which were analyzed by a Multinomial Logistic Regression model. An instrument was developed to estimate the probability that a farm belonged to one of the four defined groups based on the scheme shown in **Figure 2**.

Once the model was applied to the sample of Castilla y León, it indicated that none of the farms in the sample from Castilla y León fell into the pure extensive group: The distribution of the 17 farms is shown in **Figure 3**.

3.1 Intensive farms

Farms in the intensive group had an average of Utilized Agricultural Area (UAA) of 32 ha (see **Table 2**) and the animals did not use plant resources directly.

Figure 1.
Map of Castilla y León.

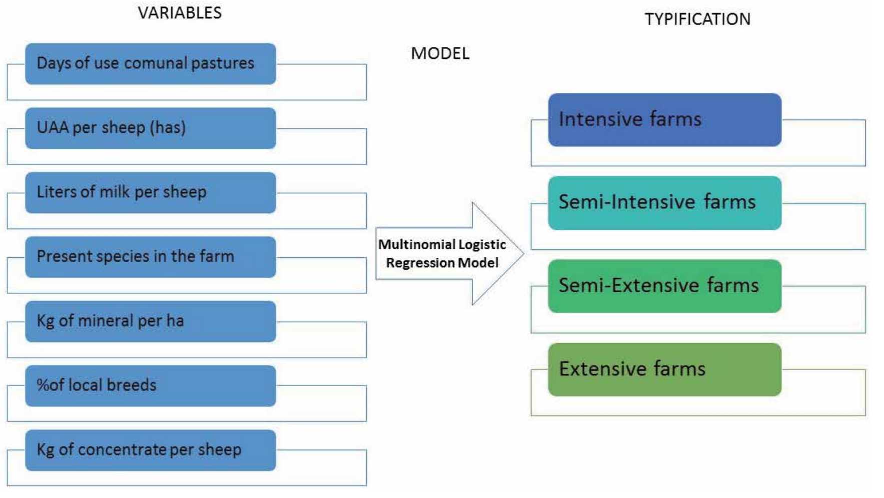

Figure 2.
Typification variables and farm typology.

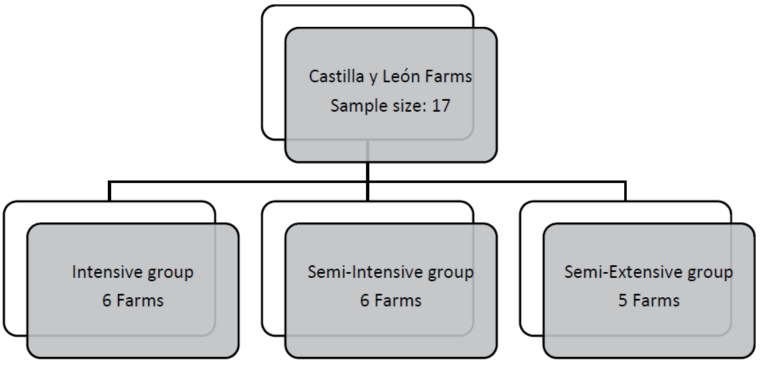

Figure 3.
Distribution of farms among typified groups.

The average agricultural area per adult ewe was 0.03 ha/ovine, which was 62% less than the average of all farms. On average, flocks had 890 adult ewes. The average total income per ewe was 298.56 euros. Capital endowments per ewe were 437 euros, which was higher than the overall average. Direct expenses per ewe were 54% higher than was the average of all farms (201.14 vs. 129.94). The gross margin per ewe was 116.50 euros (33% less than the overall average).

That group of farms has activities that require high energy efforts and emit large amounts of greenhouse gases, which is similar to the results obtained in previous studies [12] who found that the highest carbon footprint indicators occurred in farms that had management systems that were dependent on high consumption of external inputs. Milk from intensive farms had the lowest protein and fat-soluble vitamin content among the three groups. The data indicated an unhealthy lipid profile, which was due to the low proportion of green pasture in the diet. Furthermore, the group had the lowest somatic cell concentrations of the three groups. At the start of the project, a survey on the social conditions linked to each of the farms indicated that the farmers in this group had an average perception of life quality of 2.8, and a work quality of 2.20, which indicated an overall dissatisfaction that was lower than was the overall average.

	Overall average	**Group average**		**Overall average**	**Group average**
Management system results			Environmental results		
Sheep	799	824	Cost/ha x10 (MJ)	16.416	11.908
M2 Built	2412	2214	Net Cost x 1000 (MJ)	6.665	6.392
M2 /sheep	3.15	2.8	CO_2/ha (Kg Eq CO2)	17.223	7.994
AWU	3.66	4	Milk quality		
Family AWU	2.33	2	Protein (%)	5.6	5.51
UAA (ha)	68.66	68	Fat (%)	7	6.82
Own UAA (ha)	17.33	27	Omega 6 / Omega 3	4.8	5.15
External UAA (ha)	51.66	41	CLA	0.66	0.65
UAA /sheep (ha/sheep)	0.08	0.08	Alfa-tocopherol	102.42	75.63
Communal Ha	308.33	160*	Retinol	63.58	60.33
Economic results			Somatic cells	1,042.84	1,119.59
Income	240.43	255.96	Life and work quality		
Capital	378.07	366.68	Life quality	3.12	3.17
Direct expenses	129.94	111.94	Work quality	3	2.83
Indirect expenses	132.1	171.05	* two farmers		
Gross margin	149.73	200.06			
Net margin	17.63	29			

Table 3.
Characteristics of semi-intensive farms.

3.2 Semi-intensive farms

Semi-intensive farms had an average UAA of 68 ha (see **Table 3**), which was similar to the average of all farms. Two farmers use communal pastures, which had an average of 160 ha. The agricultural area per adult ewe was 0.08 ha. They had built facilities that were, on average 2,214 m2, that is, 2.8 m2 per adult animal, which is slightly lower than the average of all the farms. Average Total income per ewe was 255.96 euros. The investments made on the farm were 366.68 euros per ewe, with an inverse relationship between the intensification of production and the endowments of the capital factor per productive unit. Direct expenses per sheep were significantly lower than was the average for all farms. Indirect costs were 29% higher than was the average for all farms. The gross margin per sheep was 200.06, and the net margin was 128% higher than was the overall average.

Those farms are energy-intensive, although less so than the overall average, and emit moderate amounts of greenhouse gases, similar to the amounts reported by previous studies [12]. Milk from those farms had protein and vitamin levels that were close to the overall average. Fat levels were the lowest and somatic cell content was highest among the three groups. Those farms reported a higher-than-average life quality and a lower than average work quality.

3.3 Semi-extensive farms

Semi-extensive farms had a UAA of 106 ha (see **Table 4**). Those were farms in which the animals made more daily use of plant resources than did the other groups.

	Overall average	Group average		Overall average	Group average
Management system results			Environmental results		
Sheep	799	685	Cost/ha x 10 (MJ)	16.416	3.242
M2 Built	2412	2009	Net Cost x 1000 (MJ)	6.665	5.106
M2 /sheep	3.15	3.5	CO_2/ha (Kg Eq CO2)	17.223	2.018
AWU	3.66	3	Milk quality		
Family AWU	2.33	3	Protein (%)	5.6	5.93
UAA (ha)	68.66	106	Fat (%)	7	7.31
Own UAA (ha)	17.33	11	Omega 6 / Omega 3	4.8	2.96
External UAA (ha)	51.66	96	CLA	0.66	0.73
UAA /sheep (ha/sheep)	0.08	0.15	Alfa-tocopherol	102.42	172.79
Communal Ha	308.33	521	Retinol	63.58	74.11
Economic results			Somatic cells	1,042.84	1,119.74
Income	240.43	152.05	Life and work quality		
Capital	378.07	321.04	Life quality	3.12	3.2
Direct expenses	129.94	66.1	Work quality	3	3.6
Indirect expenses	132.1	123.52			
Gross margin	149.73	129.21			
Net margin	17.63	5.69			

Table 4.
Characteristics of semi-extensive farms.

The agricultural area per adult sheep was 87% higher than the average of all farms. On average, there were 685 adult sheep and facilities built to provide 3.5 m2/ewe, which was the highest average available area of all the farms. The total income per sheep was significantly (63.2%) lower than the average. The amount of direct expenses incurred on the farms was half of the overall average. Indirect costs were below the group average. The gross margin was slightly less than was the group average. The net margin was 32.3% of the overall result.

Those farms required less energy and emitted less greenhouse gases than did the other groups, similar results were obtained in previous studies [12]. Milk produced in semi-extensive farms had the highest protein, fat, and vitamin content levels. The lipid profile was the healthiest of the three types of farms. Milk from these farms had the highest vitamin content. The somatic cell content was close to the overall average. Life and work quality were higher than the overall average.

4. Results

4.1 Attributes results of typified groups

The Productivity attribute is related to the economic performance of the farms and their capacity to generate goods and services, and comprises 12 indicators, the results of which are shown in **Figure 4**.

The productivity attribute had a logical pattern determined by the different production systems, and the most extensive farms had the best results in the indicators directly related to environmental protection, as follows:

a. They were the most efficient in the use of direct and indirect energy.

b. They had the highest values regarding phytosanitary pressure, defined as the proportion of the UAA that is treated with this type of products, which indicates that this system did not use this type of supplement in the farm's agricultural tasks.

c. They opt for the use of organic matter as a means to provide nutrients to the soil. The group had an average of 100% of its UAA that was treated with organic matter.

d. Regarding the economic indicators, these farms required the lowest volume of milk production to achieve the reference income in the sector, and had the highest gross margin without subsidies.

The most intensive systems had those that obtained the highest value in the carbon footprint relative to the total kg of milk produced and to the net margin. That relationship is precisely what made this good result possible because these farms produce the highest volumes of milk and those that achieve the highest net margin per liter and per family work unit. Those economic results clearly verify their productivity vocation.

The weight of the capitalization, which is the importance of the structure to production, for this type of farm was lower than that of the other types. This concept is the ratio between the indirect expenses borne by the activity and the gross production, and, by obtaining higher production volumes, this expense is diluted. In addition, those farms were at the extreme of the values obtained in the

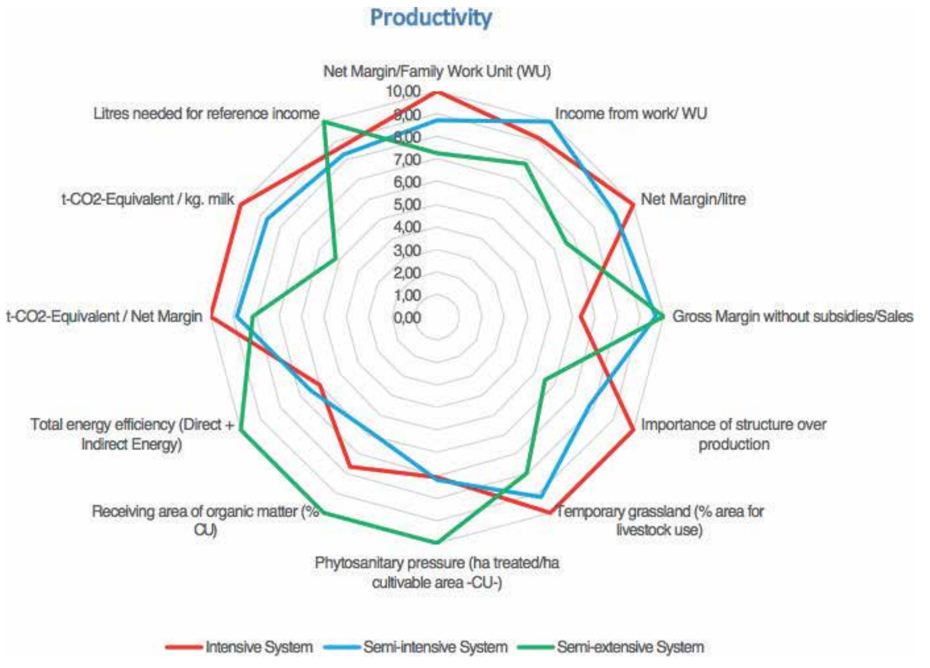

Figure 4.
Productivity attribute of typified groups.

livestock use of sown pastures because they did not use this means of production. On average, semi-intensive and extensive farms used 5.6% and 13.6% of the UAA in that manner, respectively.

The semi-intensive group occupied an intermediate position in almost all of the indicators, and obtained was optimal in the result of labor income per work unit, only, which aims to measure the remuneration of total labor (family and salaried) after deducting the capital opportunity costs.

The Stability attribute reflects the farm's capacity for innovation and its commitment to the environment (**Figure 5**).

The results of the stability attribute were highest in the semi-extensive group.

- Those farms showed the lowest importance of the costs that have financial risk, which are those affected by the interest on loans and those payable in the short term.
- They had the lowest amounts of nitrogen excreted per unit of UAA.
- They had the best slurry and manure pit management. All were professional farms that were used by the owner, exclusively with dedication.
- They had the best prospects regarding the possible continuation of the activity, possibly, because they had the highest proportion of family labor.
- Those farms reported the highest work quality.
- In aspects of grazing, such as the availability of sheepfolds, grazing of reproductive cattle and adequate grazing, the semi-extensive group had the highest scores.

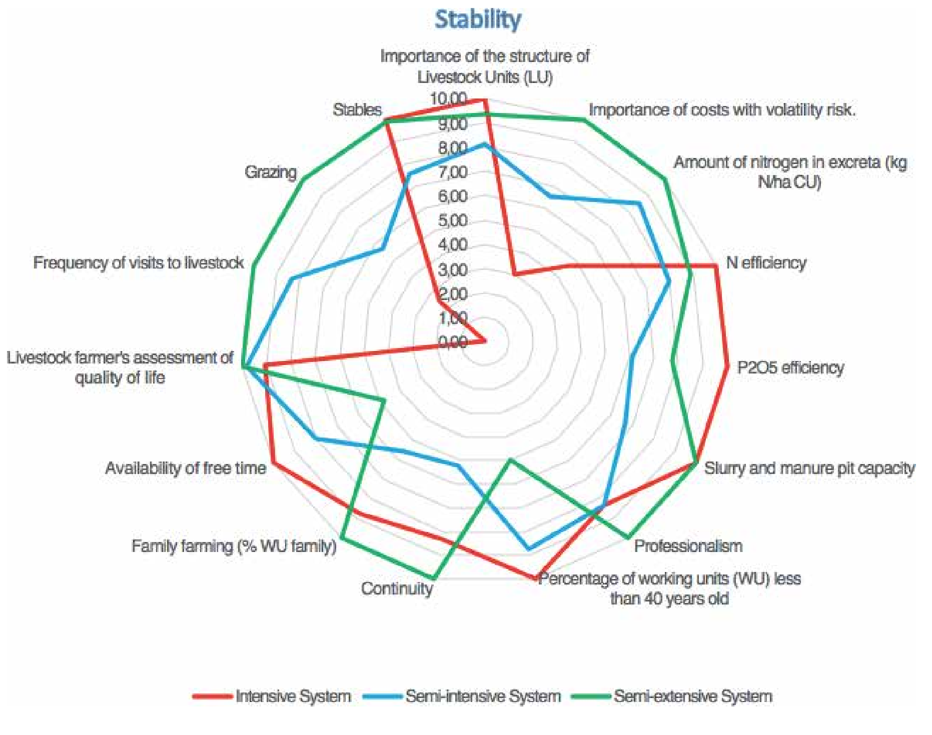

Figure 5.
Stability attribute of typified groups.

- In aspects of stabling, such as the availability of >10 m2 per livestock unit, the availability of free stall areas, bedding care and cleanliness, the maintenance of an adequate temperature and protection, and the availability of sufficient watering and feeding troughs, the semi-extensive group had the highest scores, together with the intensive group, among the three groups.

Farms in the intensive group, which had the largest herds, and more production units, had the best weight of the farm's structure on each livestock unit, following in the wake of the productivity attribute. Those farms also have the best efficiencies between nitrogen and phosphate farm outputs and inputs. They were the least aged farms, and mechanization gave them more free time, although they reported a low work quality. The semi-intensive group, as in the previous attribute, is positioned in the intermediate between the extremes marked other groups.

The Adaptability attribute reflects the flexibility of farms and their ability to adapt to a changing environment, and was the attribute in which the typified groups were most divergent (**Figure 6**).

The semi-extensive group had the best values for the following four attributes:

- Those were the farms that, according to the technician and the owner of the farm, had the highest diversification of their customers, which gave them the highest commercial independence.

- They had the farmers with the lowest stocking density per hectare of UAA.

- They had the most sustainable management in the area because they used techniques such as crop rotation or association, improvement of natural pastures, use of composting, fallow land, and integrated pest control.

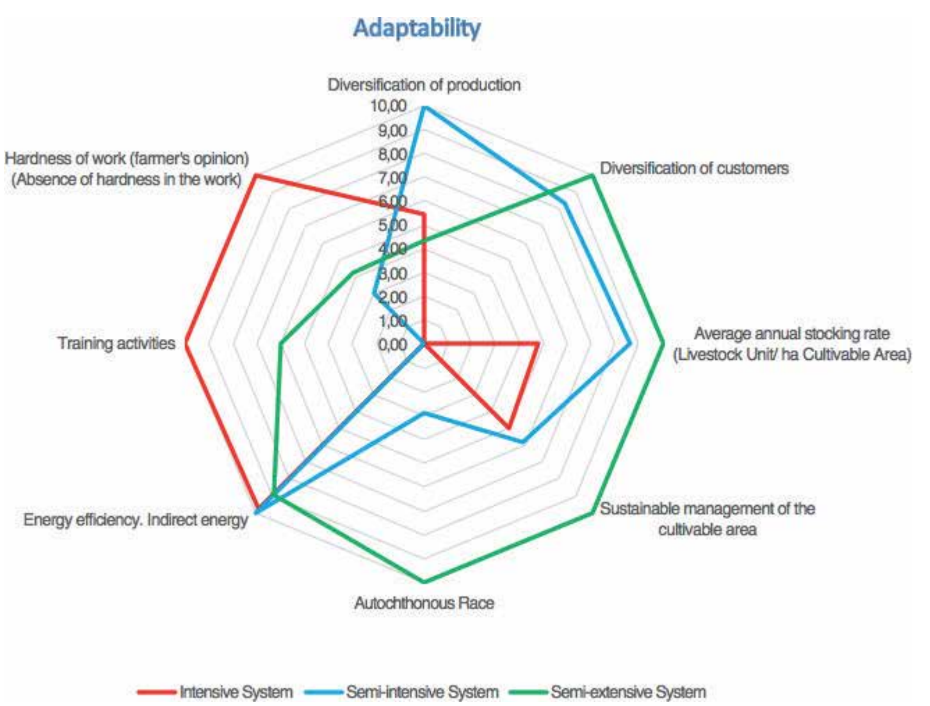

Figure 6.
Adaptability attribute of typified groups.

- Most used native breeds, which have been selected for their hardiness and are committed to maintaining the genetic diversity of the breed.

Farmers in the intensive group were those who had participated the most in training activities and those who felt that the work that they performed on the farm was the least arduous. To carry out strenuous tasks they had machinery at their disposal, which Meant that they had fewer muscular or skeletal problems. In addition, they had not had any significant work accidents, they had pre-established routines, and valued not having a boss.

The semi-intensive group had the most efficiency in the use of indirect energy and they were the most diversified in the products they produced, which allowed them to be less influenced by the volatility of milk prices as their main product.

The Autonomy attribute reflects the degree of self-management of costs and the area devoted to self-consumption (**Figure 7**).

In the Autonomy attribute, the semi-extensive group had the best values for seven indicators:

- Its farmers had the highest food autonomy, the process of re-employment of their agricultural productions gave them independence and self-management in the structure of animal feeding.

- They had the highest labor autonomy because their workforce was mostly family labor.

- They had the highest ratio of direct and indirect costs and the average price received for each liter of milk produced, probably because of the previously described process of food autonomy.

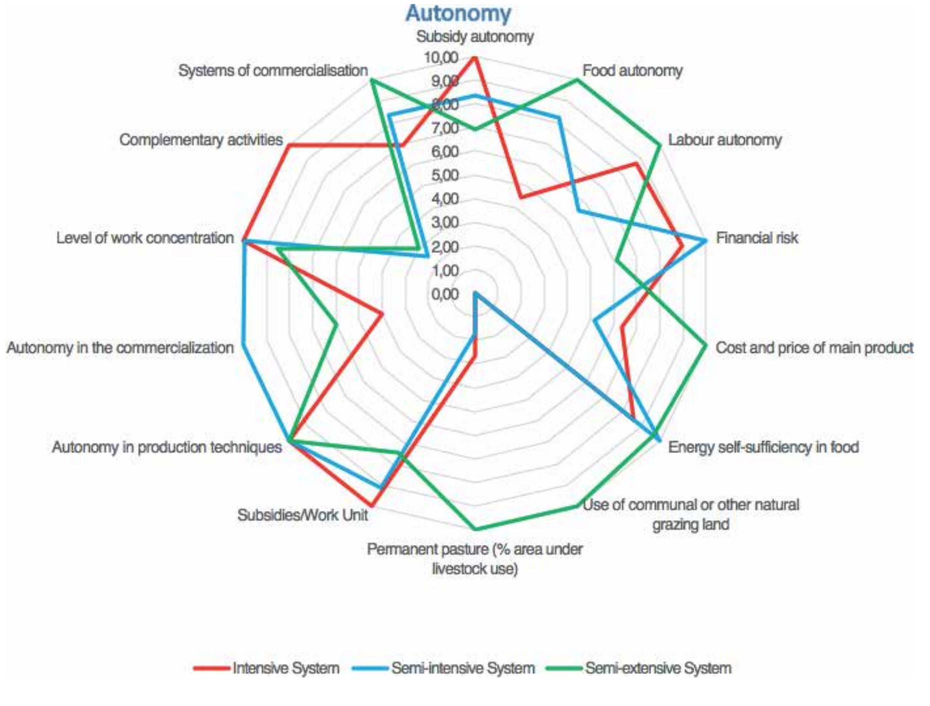

Figure 7.
Autonomy attribute of typified groups.

- They were the farms that used communal and permanent pastures for livestock feeding the most.

- In their marketing, they mostly used cooperative sales or short channels, which should have given them more marketing autonomy, but they did not feel that was the case, as is shown in the corresponding indicator.

Farms in the intensive group were the least independent on aid and subsidies. The process of production intensification produced the most stable distribution of work throughout the year because of the planning of the lambing periods.

The semi-intensive group had the best food energy balance and had the highest perception of autonomy in the management and marketing of their products, even though they were in an intermediate position within the systems they use, which means that they are mostly subordinate to industries and cooperatives. The level of work concentration was similar to that of the intensive group.

Farmers in all groups felt that they had autonomy in making decisions on the techniques and production methods that they used on their farms.

The Equity attribute reflects the social and environmental function of the farm, its commitment to the deterioration of the environment, and the gender perspective in farm management (**Figure 8**).

In the Equity attribute, the semi-extensive group had the one that obtained the best values in 10 of the 15 indicators.

- Semi-extensive farms had high natural value elements.

- They had the best results in carbon footprint per unit of productive factor (land and labor), which allows them to compensate for the poor Productivity attribute.

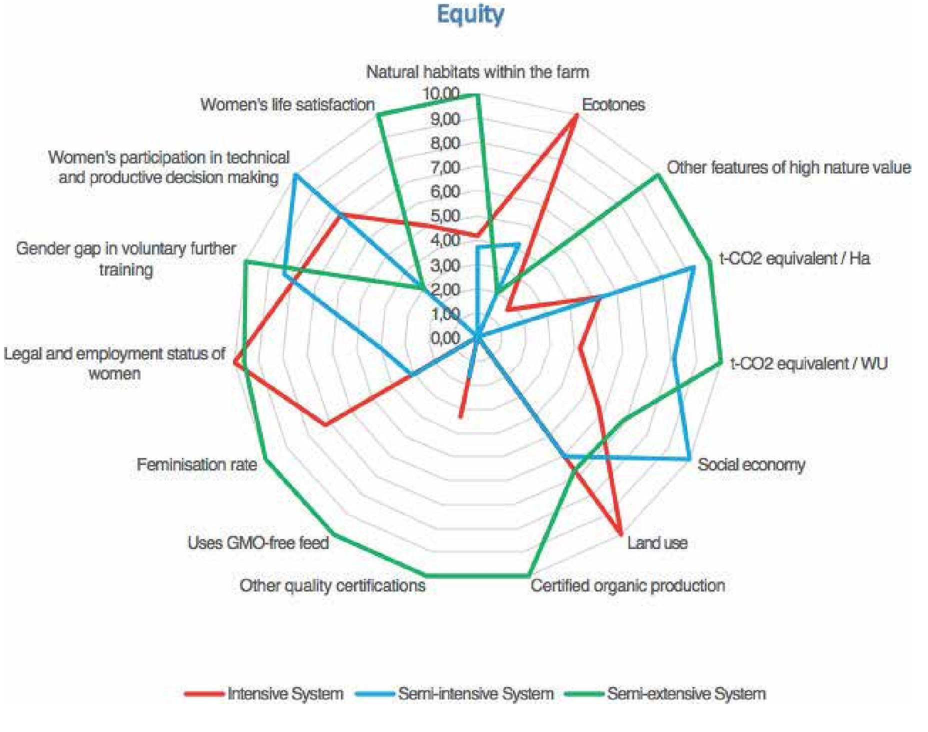

Figure 8.
Equity attribute of typified groups.

- They mostly practiced organic production, which caused them to use genetically modified organism-free food and even have productions with other quality labels.

- The semi-extensive group had the highest rate of feminization in their workforce and there was gender equity in the training processes. Women on those farms are the ones who reported the best life quality.

The intensive group had the most results in the presence of diverse ecosystems in their farms, which gave them a high biological richness, and had the lowest area managed per work unit, which is consistent with the management system to which it refers. In addition, that group had women in the best legal and working conditions, slightly higher than that of the semi-extensive group.

The semi-intensive group stands out because its farms were either associations or farms that had shared ownership, were jointly managed, and shared not only the work on the farm but also the decisions, rights, quotas, and subsidies, and had the highest for the participation of women in the farm decisions.

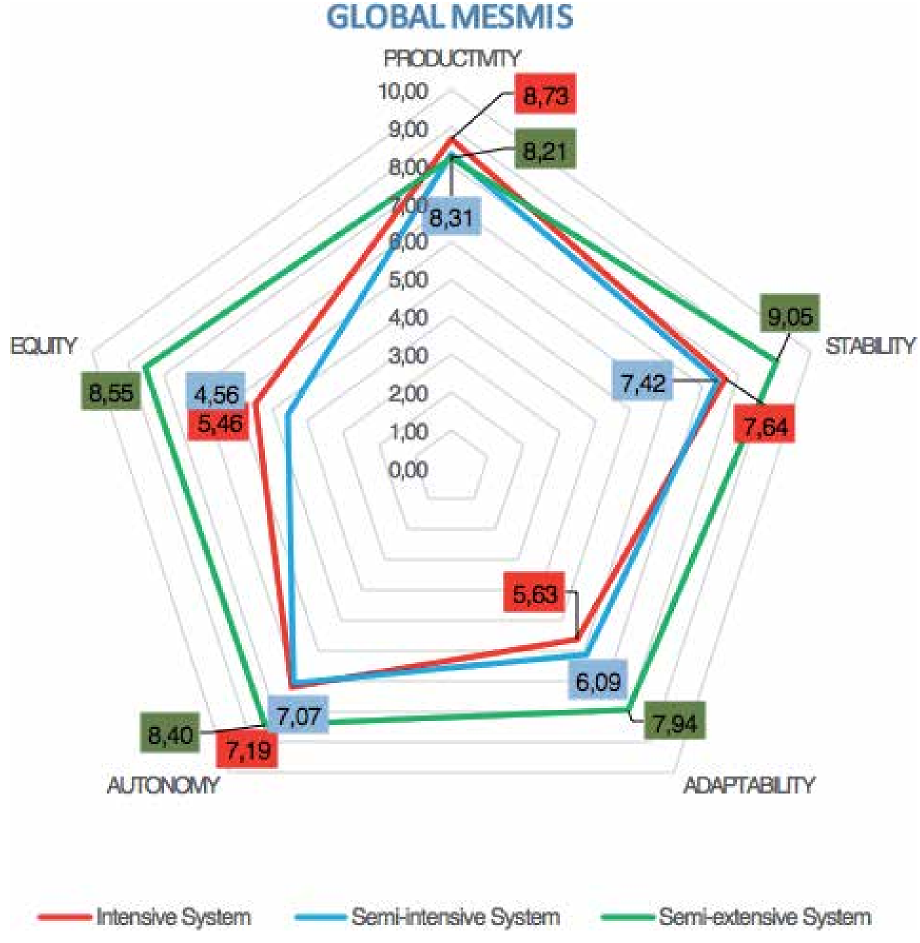

Figure 9.
Global MESMIS of typified groups.

4.2 Global MESMIS of typified groups

The Semi-Extensive group had the best Stability, Adaptability, Equity, and Autonomy, which is reflected in an almost perfect pentagon (see **Figure 9**). The Intensive group had the group with the highest productivity.

From the results, we have drawn the following conclusions:

- Productivity: This is the only attribute in which the Semi-Extensive group was penalized. Which is consistent with the existing studies that has confirmed the productivity theory that underlies management closer to intensification of production.

- Stability: In this attribute, the Semi-Extensive group has the best values in 10 of the 15 indicators, and scores 9.05 out of 10 at this pentagon vertex. The Semi-Intensive group had the lowest score. The Intensive group had the best scores in seven indicators and, overall, it slightly exceeded that of the Semi-intensive group, but was some distance from the Semi-extensive group.

- Adaptability: The Semi-Extensive group had the highest overall score (7.94) and had the highest value in four indicators. The Semi-intensive (5.63) and Intensive (6.09) groups had much lower scores. These poor results which compromised the possibilities of finding new balances that will maintain their productive capacity vis a vis of external changes.

- Autonomy: The number of indicators in which the maximum was reached was very homogeneous among the groups. Overall, the Semi-Extensive group had the highest score (8.40). This data determines, which indicates that this group has the one that shows the highest capacity to control interactions with the outside world based on its priorities, objectives, and endogenous values. The other two groups had very similar scores (7.07 and 7.19).

- Equity: The Semi-Extensive group had the highest overall score (8.55), and was placed in the highest value in 10 indicators. The other two groups had very similar scores; the Semi-intensive group did not achieve a satisfactory score and the intensive group exceeded it slightly. Thus, the Semi-Extensive group was the most responsible in inter- and intra-generational terms, which indicated greater continuity between present and future.

4.3 Global statistics of typified groups

The results of the statistical assessment of the similarities in the behaviors of the three management systems regarding the indicators of each attribute are presented in the appendix tables. The equity attribute consists of 11 indicators, for the statistical analysis these have been reduced to six by eliminating the dichotomous indicators. Thus the indicators incorporated for the statistical analysis are: Natural habitats within the farm; Other features of high nature value; t-CO2 equivalent/Ha; t-CO2 equivalent/WU; Land use; Feminisation rate.

Table 8-appendix presents the results of the normality test. Equity is the attribute that presents a normal distribution ($p > 0.05$), so the t-test is used to check for similarities or discrepancies in the indicators that make up this attribute.

For the attributes of productivity, stability, adaptability and autonomy, the null hypothesis was rejected ($p < 0.05$), which determined the need to opt for the non-parametric H test to detect possible divergences in the behavior of the three systems analyzed.

The results of the H-test for the four attributes (**Table 9**-appendix) are summarized in **Figure 10**, the main differences detected per attribute are:

- Adaptability attribute: this attribute presents 63% of differential indicators, which are directly related to management of autochthonous breeds, hardness in the work; diversification of customers; average annual stocking rate (Livestock Unit/ ha Cultivable Area); Sustainable management of the cultivable area; autochthonous race; hardness of work (farmer's opinion) (Absence of hardness in the work).

- Productivity attribute: 25% of the indicators show a differential behavior, and logically linked to the productive structure of the farms: importance of structure over production; receiving area of organic matter (% CU) and t-CO2-Equivalent / kg. Milk.

- Stability attribute: two differences detected in the indicators "importance of costs with volatility risk" and "grazing", representing 13% of the total indicators of the attribute.

- Autonomy attribute: the differential behavior is detected in the food autonomy indicator, which represents 7% of the total indicators of this attribute.

In short, the main differences are detected in indicators clearly related to the characteristics of each management system.

The results of the t-test (**Table 10**-appendix) for the indicators of the equity attribute show that the main differences are in the indicators related to sustainability, e.g. t-CO2 equivalent/Ha. The rest of the differences between management types are in issues related to gender and social involvement of the farms, which undoubtedly opens a positive way towards the concept of sustainability from a social perspective.

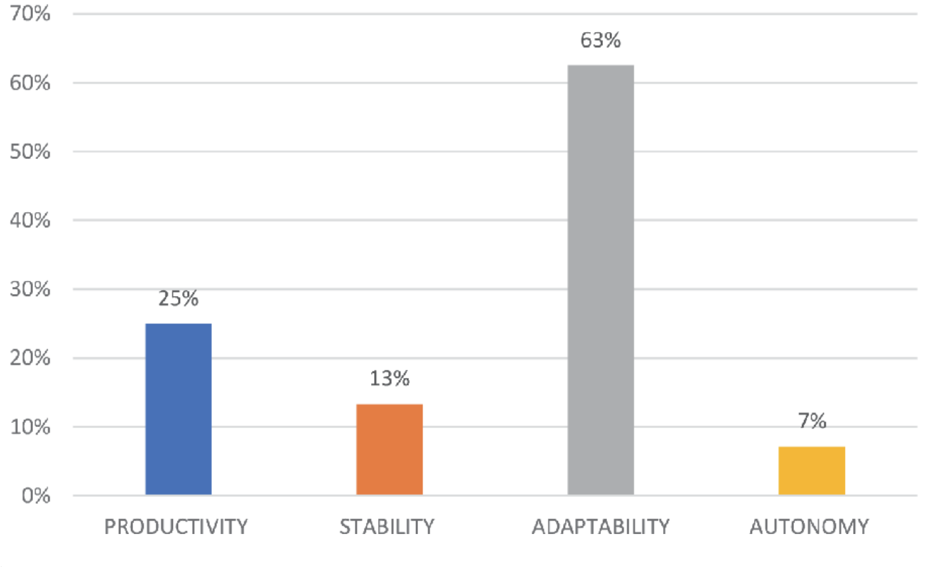

Figure 10.
Indicators for each attribute that had differential behavior (%).

The results of **Figure 9** are reflected in **Figure 10**, which statistically validates the results of the MESMIS method.

5. Conclusions

The attribute information shows that the production units of the most intensive system were the most productive. That said, the Semi-Extensive system performed well, and had an overall score of 8.21. That group was more sustainable than were the intensive systems in all attributes, especially those related to stability, adaptability, and equity.

The Semi-Extensive system responds most comprehensively to the maintenance of a living, articulated, and sustainable natural and rural environment. After the application of the proposed methods, it can be concluded that the initial typification, which was based on seven management indicators, is valid, because three groups that have very specific behaviors have been defined and confirmed by previous studies and experience.

Extensive livestock farming has characteristics [13] that were reflected in the indicators in our study:

- Extensive farming produces high-quality food products; e.g., the analysis of milk quality.

- It allows the use and preservation of ecosystems of high ecological and environmental value, such as "dehesas" and mountain pastures, which is reflected in the environmental indicators.

- It takes advantage of areas such as fallow land, stubble, mountain pastures, and grazing wasteland, which would be difficult to make better use of, which is reflected in the land use indicators.

- In areas that have arid or semi-arid climates, sheep, through traditional practices (grazing, "redileo"), make a contribution to increasing organic matter and preserving the vegetation cover of the poorest soils.

- It contributes to mitigating climate change and promotes branch grazing by the herd, which is an effective means of controlling shrub proliferation and preventing fires.

- It contributes to fixing the population and maintaining the social network in large regions that lack any other possible productive alternatives because of the difficult nature of the environment, which is reflected in the social indicators.

- Other local economic sectors derive directly or indirectly from its activity; e.g., food processing industries, handicrafts, tourism, and hotels, which depend on the maintenance of the landscapes and ecosystems that extensive livestock farming promotes, in addition to the products generated directly.

- They are the only feasible and productive activity that can sustain the important diversity of livestock breeds that are still preserved in southern Europe, which is reflected in the indicator of native breeds.

- This is the most ethical way to manage livestock because it allows the animals to experience a situation of semi-freedom in the open air, respecting the growth rate and living conditions of each species, which is reflected in the grazing ratios.

- It is a very adequate management for the resources derived from the environmental benefits it generates, which are reflected in the energy balances.

Collectively, that information indicates that this is one of the few productive human economic activities that can be truly sustainable. All of those characteristics make it necessary to treat each system individually, and to propose specific measures to promote this type of activity, which renounces some of its profitability for the sake of improving the common good; it must be economically assessed for the positive externalities it generates and its intra- and intergenerational commitment must be rewarded.

The structure of the farms and their relationships with the environment and the surrounding community are essential for the development of their activity and help in solving problems and the self-management of the productive unit because they allow the exchange of information and knowledge, the support management, and training. Generally, an increase in organizational capacity and a greater adaptation of economic, social and environmental structures would be desirable to encourage a transition towards more sustainable management.

6. Proposals for the management systems

Based on an individual analysis of each attribute the following improvement proposals are suggested:

6.1 Productivity

The Semi-Extensive group had the worst economic indicators that involve Net Margin, but not with those that involve Gross Margin, which suggests that this group has to adapt its fixed costs and the structure size to the economic dimension of its income, and especially to the size of its herds, because it is smaller than they are for the other two productive groups. Intensive farming seems to have a cost structure that is adequate for the economic dimension of its activity, even though this type of management requires more investment, but, in the cases studied, it seemed to be appropriate for the real needs of the herd.

In the case of the environmental indicators, the intensive and semi-intensive groups should make the necessary adjustments to increase their sustainability in this attribute. Intensification processes use environmentally unsound practices. Those types of farms depend on distant resources, which increases the carbon footprint and the energy costs needed for their activity. That said, because their output

Systems	Intensive	Semi-Intensive	Semi-Extensive
Kg CO2/ Ha	37.720,45	6.706,59	1.633,57
Kg CO2/ Work Unit	221.619,65	136.909,93	96.763,76
kg CO2/l Milk	1,90	2,56	4,40

Table 5.
Carbon footprint of the different systems.

volumes are much higher, their carbon footprint per unit produced or per net margin is lower; however, in the context of other types of variables such as Work Units or has handled, the results are very different (see **Table 5**) and indicate a need to transform their production methods.

6.2 Stability

In this attribute, the Semi-Intensive group had the worst results, both in social and animal welfare indicators, which suggests that farms in this group need to reconfigure management structure and work structure towards a model that provides a more adequate temporal horizon.

6.3 Adaptability

In this attribute, the intensive group has seriously jeopardized the diversification of its clients, and is extremely vulnerable to fluctuations in it. In UAA and breed management, changes are much more difficult because of the structure of its management system; however, if this idea is combined with Stability regarding the indicator that reflects the opinion of the farmer about life quality, in which the Semi-Extensive group approaches the maximum, it can be concluded that this more intense work does not reduce the quality, so the effect is relativized, although this does not diminish the need to lighten the workload. In addition, farms in the Semi-Intensive group must revise training to incorporate advances that improve farm management.

6.4 Autonomy

The aggregate results are similar. The Semi-Extensive group needs to improve its economic structure; in this case, financial risk and dependence on subsidies are the critical points. The Intensive group needs to improve its marketing systems by expanding its sales channels to allow greater independence and process management. Finally, both this and the Semi-Intensive groups have the option to improve the food sustainability of the farm by their use of pastures.

6.5 Equity

The Semi-Extensive group had excellent results, but the other two groups must make a significant improvement in this attribute, especially in gender-related issues and the women's perception of the satisfaction they derive from the work they perform on the farm.

Thanks

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Appendices

(**Tables 6**, **7**, **8**, **9** and **10**.)

1.-Productivity	2.-Stability	3.- Adaptability
1. Net Margin/Family AWU*	13. Structure importance on LSU	28. Production diversification
2.Labor income/AWU	14. Importance of costs with volatility risk	29. Client's diversification
3. Net Margin/liter	15. Nitrogen quantity from the excrement (kg N/ha UAA)	30. Average annual stocking rate (LSU/ ha. UAA)
4. Gross margin without subsidies/sales	16. N efficiency	31. Sustainable management of the UAA
5. Importance of the structure on the production	17. P2O5 efficiency	32. Local livestock breeds
6. Temporal pasture (% of land for livestock use)	18. Capacity of slurry pits and manure pits	33. Energetic efficiency. Direct energy
7. Phytosanitary pressure (has treated/has. de UAA)	19. Professionalism	35. Training activities participation
8. Land provided with organic matter (% UAA)	20. % AWU < 40 years	36. Hardness of the work (farmer's opinion) (Absence)
9. Total energy efficiency (Direct+Indirect energy)	21. Continuity	
10. t-CO2-Equivalent / Net margin	22. Family agriculture (%Family AWU)	
11. t-CO2-Equivalent / kg milk	23. Free time availability	
12. Liters required for Reference Rent	24. Farmer's assessment of life quality	
	25. Frequency of livestock visits	
	26. Regarding grazing	
	27. Regarding stabling	

Table 6.
NAIA-MESMIS correspondence.

4.- Autonomy	5.-Equity
37. Subsidies autonomy	51. Natural habitats within the farm
38. Feeding autonomy	52. Ecotones
39. Labor autonomy	53. Other elements of high natural value
40.Financial risk	54. t-CO2-Equivalent / Ha
41. Cost and Price of the main product	55. t-CO2-Equivalent / AWU
42. Feeding autonomy	57. Social economy
43. Use of common or other natural pastures	58. Land occupation (SPG/AWU)
44. Permanent pasture (% area under livestock use)	60. It makes certified organic production
45. Subsidies dependence/autonomy	61. It has other quality certifications
46. Autonomy in production techniques and modes of production	62. It uses GMO-free feed
47. Autonomy in product marketing	56. Feminization index

4.- Autonomy	**5.-Equity**
48. Level of work concentration	63. Legal and labor situation of women
49. Complementary activities	64. Gender gap in volunteer continuing education
50. Commercialization method	65. Women's participation in technical-productive decision making
	67. Degree of women's life satisfaction

Table 7.
(bis): NAIA-MESMIS correspondence.

Semi-intensive (n1 = 6);Intensive (n2 = 6); Semi-Extensive (n3 = 5)	
Attribute	**Shapiro-Wiks**
Productivity	W = 0.758 (p = 0.001)
Stability	W = 0.709 (p = 0.000)
Adaptability	W = 0.880(p = 0.032)
Autonomy	W = 0,648 (p = 0,000)
Equity	W = 0,916 (p = 0,127)

Table 8.
Normality test.

PRODUCTIVITY	**H (Kruskal-Wallis)**	**p-value**
Importance of structure over production	8,459	0,015
Receiving area of organic matter (% CU)	10,908	0,004
t-CO2-Equivalent / kg. milk	8,348	0,015
STABILITY	H (Kruskal-Wallis)	p-value
Importance of costs with volatility risk.	7,607	0,022
Grazing	7,138	0,028
ADAPTABILITY	H (Kruskal-Wallis)	p-value
Diversification of customers	7,183	0,028
Average annual stocking rate (Livestock Unit/ ha Cultivable Area)	12,084	0,002
Sustainable management of the cultivable area	7,022	0,030
Autochthonous Race	12,041	0,002
Hardness of work (farmer's opinion) (Absence of hardness in the work)	8,126	0,017
AUTONOMY	H (Kruskal-Wallis)	p-value
Food autonomy	9,613	0,008

Table 9.
H-test for productivity attribute indicators.

	t	p-value
Semi-intensive/ Intensive		
t-CO2 equivalent / Ha	−2,805	0,019
Land use	2,706	0,022
Semi-intensive/Semi-extensive		
Natural habitats within the farm	−4,393	0,002
t-CO2 equivalent / Ha	3,987	0,003
Feminization rate	−2,940	0,016
Semi-extensive/Intensive		
Natural habitats within the farm	−3,527	0,006
Other features of high nature value	−4,523	0,001
t-CO2 equivalent / Ha	2,968	0,016
t-CO2 equivalent / WU	3,089	0,013

Table 10.
t-test for equity attribute indicators.

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Section 2

Reproductive Management in Sheep

Chapter 5

Reproductive Rates of Merino Ewes and Offspring Quality under AI Program

Edward Narayan, Gregory Sawyer, Natalie Hoskins and Greg Curren

Abstract

Reproductive wastage is a major economic burden in sheep production globally, especially within Australia as livestock production systems face increased pressure from climatic variability (e.g. prolonged droughts or flooding). Sheep are sensitive to acute changes in their environment such as heat stress, which if not adequately monitored will result in significant production losses such as reproductive failure, increased parasite and worm burden, morbidity and mortality risks. Through basic and applied research in the areas of stress and reproductive physiology our team has made significant advancements in the understanding of sheep behaviour and physiological responses to acute and chronic stressors. Using minimally invasive hormone monitoring technology in combination with field based assessment of sheep health and productivity traits, our team has delivered new knowledge on how sheep react to acute environmental stress and how it impacts on sheep reproduction. In this chapter, we evaluated the fertility rates and embryo quality of Merino ewes under AI breeding program. We discuss factors such as heat stress that can impact on ewe and offspring quality.

Keywords: Reproductive Wastage, Merino Sheep, Heat Stress, Resilience, Embryo Quality

1. Introduction

Merino ewes account for 75% of all breeding ewes in Australia, comprising of those used for high quality fleece production, as well as for the production of first cross lambs for the meat market [1]. Despite Australia's high usage of this breed, the reproductive performance of merinos is often described as being substantially lower than those of other breeds [2–4]. Many studies have attempted to understand the sources of this poor performance, in the hope that by better understanding the causes of the loss, that they can better implement strategies to mitigate the losses.

Kilminster and Greeff [5] found that significantly lower rates of conception were found in Merino ewes who were joined at only 8 and 9 months of age, when compared to their same age Dorper and Damara counterparts. Ewes that were maiden, that is, having their first lambs, were also more likely to have lower success rates [3, 6]. In these studies, this conception rate drastically increased as the ewes matured and became experienced mothers. A study [7] into the reason for the increasing conception rate with age and amount of parturitions found that the rate of cervical passage, as is used for transcervical artificial insemination, increased with increasing parturitions due to cervical stretching. This study did not observe ewes beyond 3 parturitions so did not observe if this cervical stretching may cause problems into older age. A 2015 study [8] of 22,758 Churra ewes, a Spanish dairy sheep breed, reported that ewes are most fertile between 1.5 and 4.5 years of age. Ewes older than 4.5 years often would have had numerous parturitions, a factor that Anel determined was a contributing factor to the decline of fertility.

Ewes that conceive multiple foetuses experience a compounding risk of poor reproductive performance, as there is a high risk of losing one foetus between pregnancy scanning and parturition. Those that are able to keep both foetuses until parturition are still at risk of losing a lamb during the sensitive post-parturition period [3, 9].

Sheep are considered to be seasonal breeders. They experience marked changes in their behaviour, endocrine and ovulatory levels between their ovulatory and anovulatory seasons. Hormonally, luteinizing hormone (LH) remains at a relatively constant level, although the pulsation rate is lowered. Plasma progesterone is essentially undetectable during anoestrus [10]. Farmers are able to manipulate this seasonal variation through the use of light pulses and melatonin supplementation to create short days and long days [11]. Oestrus is stimulated after the longest day of the year, at which point the day-length begins to shorten. In Australia, this is late December. Fogarty (year) found that oestrus and fertility peaked during autumn (February) joining with the lowest fertility rate being seen in Spring (October and November) joining's.

The impact of the thermal environment on fertility and conception rate is not a new concept. In 1964, Dutt placed ewes in a temperature-controlled room prior to and/or after breeding and studied their responses [12]. The results showed a significantly lower rate of fertilisation in the heat-treated ewes. Placental research has similarly shown that high ambient temperatures reduce success rates. Bell et al. [13] and Early et al. [14] found that placental development is reduced by up to 54% in heat-treated ewes, which had a carry-on effect to the offspring: as the placenta was smaller, the foetus's growth was stunted. Studies by Kleeman et al. [3, 15] found that fertility was negatively influenced by the number of days ambient temperatures were above 32.0°C during mating, suggesting that high ambient temperatures may reduce embryo survival.

In spite of this large body of research into reproductive wastage from the perspective of gestational or pre-weaning loss, as well as genetic quality concerns, there is limited research into the impact of the ewe on the quality of her offspring, especially long-term studies that look beyond weaning and into adulthood. This study aims to fill this gap by determining factors in the ewe that will lower her reproductive success and the quality of offspring using lifetime production data from the MerinoLink Limited Sire Evaluation Program.

2. Methods

2.1 MerinoLink limited sire evaluation program

The MerinoLink Limited Sire Evaluation Program is designed as a standard sire evaluation trial that follows progeny of selected Merino Superior Sires (MSS), assessing their characteristics at 10 months and 22 months of age, in line with the Australian Merino Sire Evaluation Association. The selected traits are those deemed to be of value to breeders and commercial producers. For the purpose of our study, we do not know which progeny belong to which sire, as this was deemed a potentially confounding variable if sire identification was known.

2.2 Study group

The 2016 breeding season was conducted at a commercial farming property in Jugiong, NSW (−34.770150, 148.304470). Ewes were managed as one contemporary flock until 10 days before lambing, when they were separated into their respective sire groups. This was to ensure that there was no external influence by environment or pasture type and quality. The ewes were also given equal opportunity and access to a supplementary feeding program. The feeding program was designed to sure that nutritional requirements were met throughout all stages of gestation. The researchers were supplied with the following data from the research data providers; it is thus mixed aged ages spread evenly across all sire groups. The exact age grouping for each sire is unknown. The foundation ewes that were used to generate the 2016 and 2017 drops were sourced from five flocks and allocated evenly across all sire groups, the foundation ewe base consisted of:

- Bluechip ewes – approximately half of the ewe base came from two drops of ewes that were the result of a previous sire evaluation program. All ewes have full pedigree and ASBVs.

- Pooginook - 155 2, 3 and 4-year-old ewes were selected from 1,050 stud ewes. They consist of single mated ewes (104) and syndicate mated ewes (51). All ewes have ASBV's and are structurally sound. The average MP+ index is 143.

- Commercial Pooginook - 200 commercial Pooginook blood ewes were selected out of 750. The ewes had been measured for micron and greasy fleece weight and reared a lamb.

- Bundilla - 150 ewes were selected from an ewe base of 800 stud ewes. All ewes had reared a lamb and consisted of 3 and 4 year old ewes with an average MP+ 140.

- Centre Plus - 150 ewes were selected from a ewe base of 350 stud ewes. The ewes have an average MP+ of 158.

Insemination occurred in a shed environment on the 23rd February 2016 with a total of 107 ewes each being inseminated *via* artificial insemination to one of twelve randomly selected sires. The insemination day ran for a total of 5 hours and 22 minutes, from 10:48:19 to 16:10:23. Breaks were had at 11:48 for 41 minutes, 13:11 for 16 minutes and 14:01 for 1 hour and 8 minutes. All sires were previously evaluated for semen quality. Each ram was given 50 mixed aged ewes as noted above. In the 2016 trial the age breakdown of the sires used were 2011 – 1, 2012 – 3, 2013 – 3, 2014 – 3, 2015 – 5; 2017 trial 2011 -1, 2013 – 3, 2014 – 4, 2015 – 5. This was from a sire evaluation trial and various sires semen was used from various studs.

At time of the research being conducted the standard AI protocol in Australia based on AllStock Artificial Breeding Services (www.allstock.com.au) was implemented. All laparoscopic AI procedures conducted on the ewes were performed by the same qualified AI technician. On the day of AI, ewes were sedated with 0.05 mg/kg of Zylazil injection 20 minutes prior to the AI procedure. Ewes were then artificially inseminated via laparoscopy, with frozen semen. Semen quality was assessed post thawing by a qualified veterinary surgeon. Rectal temperature was recorded twice (immediately before sedation and 30 min post AI). All laparoscopic AI procedures conducted on ewes in this study were performed by a qualified veterinary surgeon.

Pregnancy scanning occurred on the 26th May 2016, where ewes were scanned as being dry (not pregnant), pregnant with a single lamb or pregnant with twins. Ewes gave birth between the 22nd and 30th July, lambs were marked on the 2nd September 2016, and weaning occurred on the 29th October 2016. The data supplied to the researchers was from an Australian Industry trial that the researchers had no influence on the methodology or overall design. Authors of this paper understand that pregnancy can be detected post 45 days in sheep and would recommend this to be of best practice. However, it is believed that 92 days would have allowed back up rams to inseminate ewes that had lost a lamb early after insemination and be drafted off from the trial mob with small embryos. All ewes are commercial ewes were being used in the trial.

The 2017 breeding season was conducted at a property south of Yass NSW (−34.977260, 148.855810). A total of 800 ewes were managed in the same manner as the 2016 flock, until 10 days before parturition, when they were divided into 5 mobs. Data sets for 531 individuals were made available for our study, of which 136 were randomly selected to be used for further data collection and analysis.

Insemination occurred in a shed environment on the 28th February and 1st March 2017, where the 800 ewes underwent artificial insemination to one of sixteen sires, selected at random. The first day began at 7:51:30 and ran to 14:32:51 with breaks at 9:08 (37 minutes) and 11:38 (66 minutes). The second day began at 7:18:03 and finished at 13:06:40, with breaks at 9:06 (47 minutes) and 11:38 (65 minutes).

The 2017 flock were scanned for pregnancy confirmation on the 24th May 2017. All ewes gave birth between 28th July and 8th August 2017. Marking occurred on the 1st September 2017, where their sex was recorded and lambs were weaned from the ewes on the 9th November 2017. At the time of weaning, the data for the category "weaning weights" was collected. Post-weaning weights were collected when the lambs were 6.5 months old (14th February 2018), and yearling weights were taken when the lambs were 12.5 months old (27th June 2018). Finally, fleece data, including fibre diameter, staple length, staple strength and wool weight (greasy and clean) were obtained at 10 months of age, on the 21st May 2018.

For the 136 selected for further analysis (study group), we obtained data on the year of birth of mother, diagnosis as twin or singleton at the time of pregnancy ultrasound and the body temperature (rectal) of mother at insemination.

2.3 Types of data collected

For the purpose of this data set, lambs considered to be of the "weaning" age category were between 6 weeks and 4 months of age (42 to 120 days). Those in the "post-weaning" category were between 4 and 10 months of age (120 to 300 days). Finally, those in the "yearling" category were between 10 and 13 months of age (300 to 400 days).

Fibre diameter refers to the measurement in micrometres (microns) of the wool fibres from an individual sheep. Merino sheep are a breed specifically designed for their fine wool diameter, aiming for 20 microns or lower; a lower micron size denotes a finer wool, and thus a higher quality wool. Staple length is the length in millimetres of a piece (staple) of wool. The length of a staple determines its end use – whether it will be used for weaving or knitting. Staple strength refers to the amount of force required to break a wool staple, recorded as Newtons per kilotex

(Nkt). A kilotex refers to a staple of a given thickness. This informs us of the efficiency of wool processing; how likely the fleece is to break during processing.

All fleece, as shorn straight from the sheep, including skirtings is called greasy fleece weight. As this weight occurs before cleaning, it includes all fibre, vegetable matter, dirt, wax and other environmental contaminants. Clean fleece weight is the weight after these contaminants have been removed, and the fleece has been washed. It is calculated using the formula:

$$\text{Clean fleece weight}\,(\text{kg}) = \text{greasy fleece weight}\,(\text{kg})\ \text{x washing yield}\,(\%)$$

2.4 Statistical analysis

All data was analysed using IBM SPSS Modeller (SPSS Inc. 1994). A covariate analysis and chi square analysis were performed for both the 2016 and 2017 flocks to analyse the fertility rates for time of day of insemination. The 2017 flock underwent further analysis, including regression analysis of bodyweight, greasy and clean fleece weights, yearling fibre diameter and temperature at insemination. One sided T-tests were used to assess yearling staple strength, staple length, ewe body temperature at insemination vs. progeny sex and body weight at weaning. Year of birth of mother was analysed using a Fishers one-sided exact test. Differences were considered significant at $P < 0.05$.

Conception rate (also referred to as "artificial insemination rate" or "fertility rate") is calculated using the formula: conception rate = (successful conceptions)/(total ewes inseminated)

3. Results

3.1 Fertility in 2016 flock

The 2016 flock (n = 107) had an artificial insemination success rate of 55% (n = 59), with a further 40 ewes conceiving via a backup ram after artificial insemination. This combined total lead to a total fertility rate of 93% (n = 99).

The earliest period of the day (period 1) had the most conceptions, with 40.67% (n = 24) of all successful inseminations occurring in this period. This was a rate of 73% of the period 1 ewes that conceived. The lowest period in the day was period 2 with 11.86% of all conceptions occurring in this period. This was a rate of 29% of the period 2 ewes that conceived; this different is statistically significant

	Period 1	Period 2	Period 3	Period 4	Total
Successful conception from AI	24	7	9	19	59
Failed conception from AI	9	17	10	12	48
Fertility rate for period	73%	29%	47%	61%	55%
Singletons	11 (46%)	1 (14%)	5 (56%)	10 (53%)	27 (46%)
Twins	13 (54%)	6 (86%)	4 (44%)	9 (47%)	32 (54%)

Table 1.
Fertility rates of merino study ewes (n = 107) via artificial insemination in 2016 by period of day inseminated. Singleton vs. twin rates provided based on scanning data for those that conceived.

(Fishers one-sided; P = 0.001). However, as the day progressed, the conception rate improved, with 32% (n = 19) of all conceptions, 61% of the period's conceptions, occurring in period 4 (**Table 1**). The difference in conception rate between period's 2 and 4 was statistically significant (Fishers one-sided; p = 0.018). The difference between period 1 and 4, 2 and 3, and 4 and 3 were not statistically significant (Fishers one-sided; p = 0.252).

Despite this lower rate of conception in period 2, this period produced a higher rate of lambs, with six of the seven period 2 ewes having twins. The proportions of twins and singles in the other three periods (periods 1, 3 and 4) were all similar and there was a borderline statistically significant difference between period 2 and all other periods (Fishers one-sided; p = 0.082).

3.2 Fertility in 2017 flock

The 2017 flock had a total conception rate of 87% (n = 180 lambs at scanning). 66% (n = 138) of these conceptions occurred via artificial insemination, with the remainder of lambs being conceived via the use of a back up ram (n = 42 lambs at scanning). Only 28 ewes failed to conceive during this period via either artificial insemination or after spending two cycles with a back-up ram.

In 2017, the artificial insemination was performed over three periods. 36.9% (n = 51 lambs at scanning) of all lambs conceived, were from ewes inseminated in the first period. The within-period conception rate was 70.8%. The middle period (period 2) contributed the highest conception rate of the day, with 45.6% (n = 63 lambs at scanning) of all lambs conceived on the day, with a within-period success rate of 77.7%. The final period (period 3) had the lowest conception rate, with 17.3% (n = 24%) of lambs being conceived in this period. The ewes that were inseminated in the afternoon period (period 3), including those that failed to conceive *via* artificial insemination, but that went on to conceive via the use of a back-up ram had the highest twinning rate, with 55% of lambs in this period scanning as twins. This was followed closely by the middle period (period 2) which had a twinning rate of 39%, followed by period 1 which had a twinning rate of 49%. The difference between the periods of insemination performed before the major break of the day (periods 1 and 2) and the afternoon period (period 3) was statistically significant (Chi2; p = 0.0005) (**Table 2**).

3.3 Year of birth of mother

In 2017, both the eldest ewes (born in 2011) and the youngest ewes (born in 2014) each contributed 13% (n = 24 each) of lambs in the 2017 conceptions. Both

	Period 1	Period 2	Period 3	Total
Successful conception from AI	51	63	24	138
Failed conception from AI	21	18	31	70
Successful conception from use of back-up ram	—	—	—	42
Singletons	32 (51%)	34 (47%)	20 (45%)	86 (48%)
Twins	31 (49%)	39 (53%)	24 (55%)	94 (52%)

Table 2.
Fertility rates of merino study ewes (n = 136) via artificial insemination and back-up ram in 2017 including the rate of singleton and twins from both the artificial insemination and ram back up usage.

	2011	2012	2013	2014	Total
Singletons	13 (54%)	21 (37%)	39 (52%)	13 (54%)	86 (48%)
Twins	11 (46%)	36 (63%)	36 (48%)	11 (46%)	94 (52%)
Total	24	57	36	24	180

Table 3.
The effect of year of birth of mother on the conception of single or twin pregnancies.

of these also had a twinning rate of 46% (n = 11 each). The most fertile ewes were those born in 2012, with 31.7% (n = 57) of lambs conceived by these ewes, of which 63% (n = 36) were twins. The 2013 born ewes contributed 20% (n = 36) of lambs in 2017, with 48% (n = 36) being twins. The difference in fertility between 2012 ewes and all other ewes was statistically significant (Fishers one-sided; p = 0.033), however 2011, 2013 and 2014 ewes were not significantly different from each other (**Table 3**).

3.4 Temperature at conception (2017)

The distribution of maternal body temperature at time of conception was slightly skewed from normal (**Figure 1**). The ewes body temperatures (rectal) ranged from 39.0°C to 40.9°C, with a mean of 39.78°C, and a similar median of 39.7°C. We considered temperatures over 40.2°C to be abnormal, as only 11% (n = 15) had temperatures at or over this point. The variation in body temperatures did not produce different rates of male or female progeny (t-test; p = 0.021).

Regression analysis showed no statistical significance for temperature*all_weaning_weight (p = 0.506), temperature*postweaning_weight (p = 0.215), temperature*male_weaning_weight (p = 0.783), and temperature*male_postweaning_weight (p = 0.532). Temperature*female_weaning_weight was not significant, but had a lower p-value than the other weaning samples (p = 0.281) and

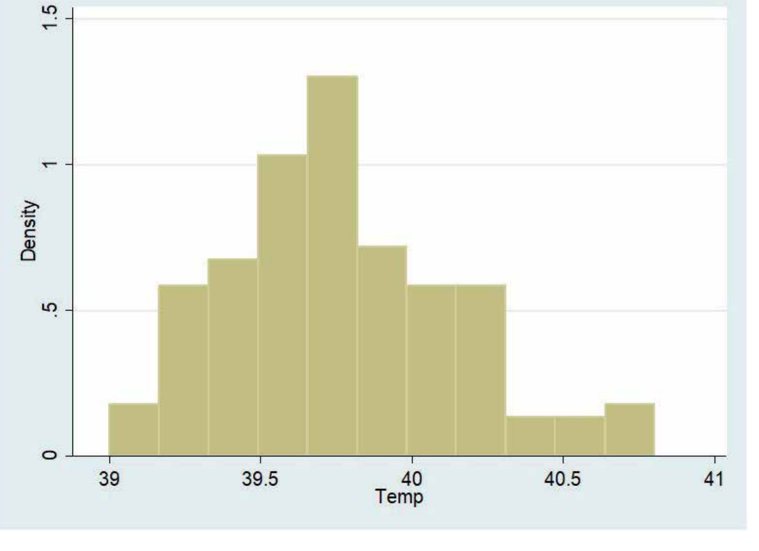

Figure 1.
Histogram of temperature of 2017 ewes at conception. Mean = 39.78°C. temperatures over 40.2°C were considered abnormal.

temperature*female_postweaning_weight was significant ($p = 0.021$). No regression was performed for yearling weights.

Conception temperatures above and below 39.5°C had a borderline significance for female progeny (t-test; $p = 0.13$), with a difference in post-weaning weight of +0.46 kg. Conception temperatures above and below 40.2°C likewise showed statistical significance (t-test; $p = 0.033$) with a difference in post-weaning weights of +1.09 kg.

Weaning weights for female progeny likewise showed non-significance (t-test one-sided; $p = 0.281$), with a difference in average weaning weight for both low (<40.2°C) and high (>40.2°C) maternal conception temperature of +0.41 kg (low = +0.06 kg; high = −0.36 kg). Finally, yearling weights showed significance, for conception temperatures above and below 39.5°C (±1.9°C) (t-test; $p = 0.0300$) and above and below 40.2°C (t-test; $p = 0.0073$).

3.5 Pregnancy scans (2017)

At the time of scanning, there was a 1:1 ratio of singleton and twin lambs, with 54 ewes scanned as being pregnant with singletons and a further 54 scanning as having twins. Of these 54 twin-scanned ewes, 48% (n = 26) lost one of their lambs, having only a single survive to birth.

3.6 Progeny sex (2017)

In the study group, the ratio of males to females was 0.84:1, with 62 males and 74 females being born.

3.7 Progeny weight (2017)

Regression analysis found no significant difference in each age category (weaning, post-weaning and yearling) between the study and non-study groups. As yearlings, however, there were proportionately more progeny in the study group that were under the mean weight than those in the non-study group, who showed a higher range of weights (**Figure 2**).

The change in weight between age categories was not statistically significant through regression analysis, however the range of weight changes is notable – some sheep gained weight between age groups, whilst others lost weight between ages. The widest range of weight changes, including loss of weight, occurred from weaning to yearling age (**Figure 3**).

3.8 Fibre diameter, length and strength (2017)

There was no statistically significant difference (t-test; $p = 0.12$) in yearling fibre diameter (YFD) between the study and non-study groups. The study group averaged +0.073, whilst the non-study group averaged −0.006. A regression analysis showed no relationship between yearling fibre diameter with the mother's temperature, year of birth, or the sex of the progeny tested. There was, however, a highly significant relationship with whether the progeny was scanned as a twin or singleton, and its yearling fibre diameter. Those scanned as twins had an average YFD of −0.084, and those scanned as single lambs averaged at +0.398.

The final yearling fibre diameter analysis was a regression of yearling fibre diameter versus scan fecundity (single or twins) and sex. This found that the sex*fecundity interaction was not significant, nor the sex*twinning interaction, but

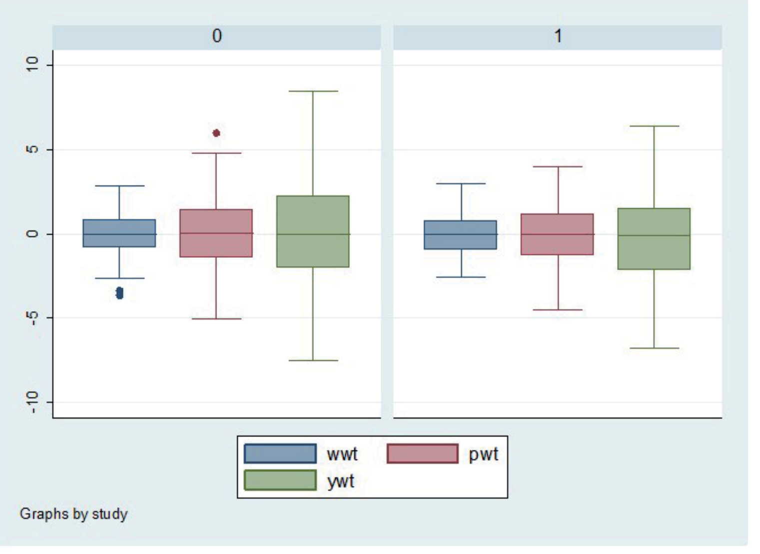

Figure 2.
Boxplots of bodyweights at weaning (wwt = blue), post-weaning (pwt = red) and yearling (ywt = green) for study and non-study groups (study group = 0; non-study group = 1).

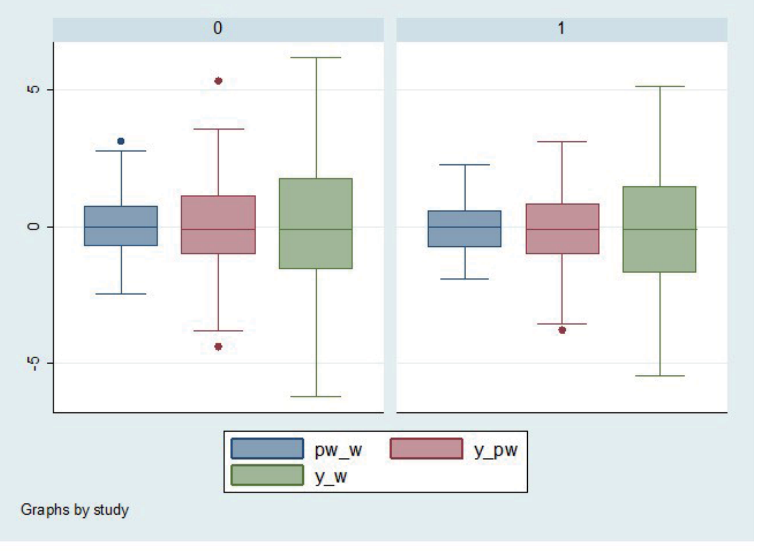

Figure 3.
Boxplots of change in bodyweights in study (0) and non-study (1) progeny. Pw_w (blue) = weaning to post-weaning; y_pw (red) = post-weaning to yearling; y_w (green) = weaning to yearling.

was the for sex*singletons. Females had a mean yearling fibre diameter of +0.057, and males had a mean diameter of +0.524. The singles showed a marked bimodal distribution, but not those born as twins (**Figure 4**).

3.9 Staple length and staple strength

Yearling staple strength was significantly greater in the study group (t-test; one sided p = 0.032) with the study group's mean staple strength at +0.0621, and

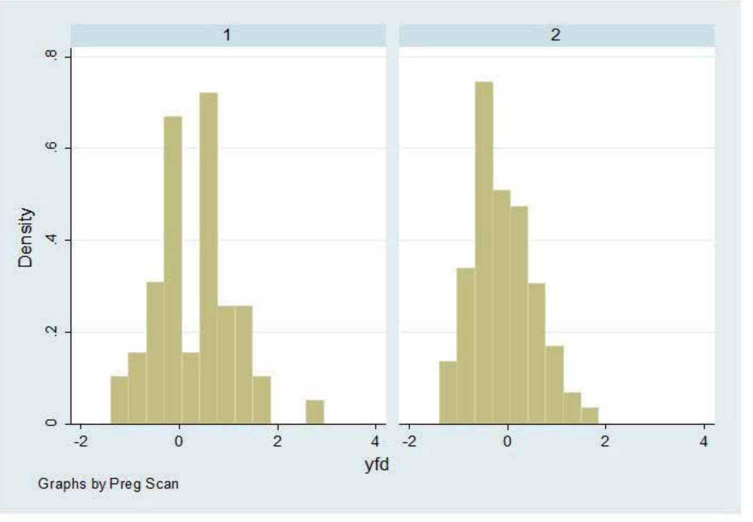

Figure 4.
Histogram of yearling fibre diameter by scan fecundity (1 = singletons, 2 = twins).

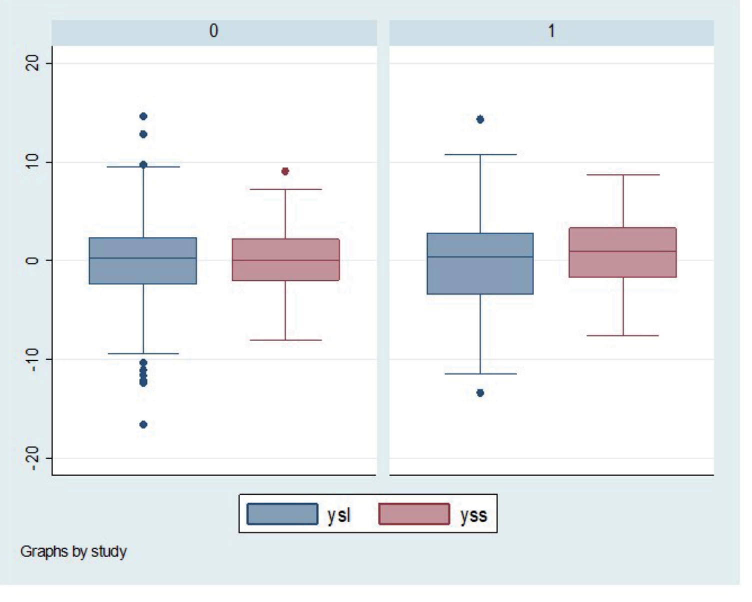

Figure 5.
Boxplots of yearling staple length (ysl = blue) and yearling staple strength (yss = red).

the non-study group's mean at +0.033 (**Figure 5**). Yearling staple length was not significantly different between study and non-study groups (**Figure 5**).

4. Discussion

The MerinoLink program with its comprehensive range of collected data has been a powerful tool for understanding the relationship the ewe has with her progeny. In the present study, we found that the youngest ewes (born in 2014) and the eldest ewes (born in 2011) had the lowest conception rates (13% each). The low rate of conception from young ewes is consistent with data presented by Kleeman and Walker [3, 15] who found that maiden Merino ewes had a fecundity rate up to 11% lower than the mature ewes of their study. Additionally, an Egyptian study by Abdel-Mageed et al. [6] found that maiden ewes (of the Rahmani and Barki breeds) had a reproductive wastage rate as high as 70% in maiden ewes (vs. 42% for mature ewes). Mature ewes in both of these studies had higher successful conceptions and lower reproductive wastage, as was seen in our study with the 2012 and 2013 ewes (31.7% and 20% respectively). The ewes born in 2012 also had a significantly higher twinning rate with 63% of lambs born as twins. Kleeman and Walker [3, 15] reported a similar result and found that this was due to a higher ovulation rate with more multiple ovulations, as is often required for twins to be conceived.

The time of day of conception was an important factor for the overall conception rate as well as the rate of singletons and twins being conceived. The 2016 flock had the highest conception rate in the first period of the day (73% success), followed by the last period of the day (61% success). The middle two periods experienced relatively low rates of conception (29% and 47% respectively). Despite this low rate of conception in the middle periods, period 2 experienced the highest rate of twins conceived, with 6 out of 7 (86%) of ewes conceiving twins. Unlike the 2016 flock, the 2017 flock saw the highest conception rate in the middle period (45.6% of all AI conceptions), followed by the first period (36.9% of AI conceptions). The final period of the day had only a 17.3% conception rate from AI. Overall, the 2017 flock had a conception rate 11% higher than 2016 (2017 = 66%, 2016 = 55%), and was 5.9°C cooler than the 2016 insemination day.

Previous studies suggest two potential lines of reasoning for this daily variation. The first potential line is that of daily melatonin variation. Melatonin, synthesised and secreted from the pineal gland is the hormone responsible for seasonal fertility in sheep, and is regulated by the day-night cycle. Seasonally, the study ewes were in prime fertility, however daily melatonin variations are rarely considered as a potential fertility factor. Melatonin implants [16–19] have been shown to not only prolong the breeding season, but also to improve the proportion of successful conceptions and the fecundity rate. Melatonin has been identified as a component required for in vivo oocyte maturation, as it has been quantified in the granulosa cells of healthy oocytes (Tamura et al., 2012, as cited in [20]). Tamura et al. and Peris-Frau et al. (2017, as cited in [20]) also suggested that melatonin may act as an antioxidant in the oocyte follicle, protecting it from reactive oxygen species (ROS), which are known to cause damage to oocyte and granulosa cells. Peris-Frau's studies added melatonin to the collecting media during ovary transport and found that the rate of degradation declined significantly. Whilst we did not measure melatonin levels in our study ewes, previous studies of daily melatonin changes indicate that melatonin is at its highest concentration early in the morning, declining until the evening when an animal returns to sleep, at which point the levels can be replenished.

The second line of reasoning involves the ambient and ewe temperatures. Decades of studies have shown that ewes have far higher conception rates when not exposed to high ambient temperatures and heat stress. Our present study did not have a heat treatment or comparison to cooler days, with all ewes being inseminated on the same day. We did, however, take rectal temperatures at the time of insemination, which allowed us to observe the temperature of ewes. There are many different numbers given for the "normal" rectal temperature of a sheep, with some suggesting as low as 38.3°C [21, 22]. The Australian Veterinary Association [23] suggests that a normal resting rectal temperature should be approximately 39°C, with mild heat stress beginning at 39.5°C. In the present study, the rectal temperature had a mean of 39.78°C, ranging from 39.0°C to 40.9°C. No ewes were reported as having low rectal temperatures and temperatures over 40.2°C were considered abnormal, with only 11% having temperatures over this range. The 11% of ewes with temperatures over 40.2°C are considered by the AVA to be in moderate to severe heat stress. Although the ewes were inseminated in a shed condition, the shed undergoes natural temperature variations throughout the day, potentially explaining this ewe temperature variation, and thus conception rate.

The biggest impact that abnormally high temperatures had on our study group was that female progeny were born significantly smaller and remained smaller even into yearling age. This has a definite potential impact for the merino industry, both in terms of available surface area for which to grow fleece, for capacity to carry lambs, and even fertility. There appears to be limited research about as to the potential reasons for this. One study considered the effect of heat on the placenta [13, 14]. This study found that high heat exposure caused placental stunting of up to 54%. They found that placental RNA and DNA content were reduced as were maternal plasma concentrations of progesterone, cortisol and placental lactogen. However, if this was the cause of smaller females, we would expect to see this in the male progeny as well.

Unfortunately our study had several confounding variables that we could not eliminate. Specific data relating to ram usage over each ewe was unavailable due to the sensitivity of that information, but this meant we were unable to consider the impact of the ram itself. A 2005 paper by Anel et al. studied the potential factors influencing the success or failure of artificial insemination. Overall, they found that the year, season and the technique of AI were the most important factors that would predict success or failure of insemination. Therefore, we suggest that future studies should consider minimising these confounding variables to ensure consistency and accuracy.

Based on our results, we conclude that the lifetime data program can be a highly effective tool to understand the impact of the parents on the progeny, both in terms of genetic variation and environmental factors. Future studies should consider using this method to observe a wide variety of factors including pre-conception, post-conception, throughout gestation and into the adulthood of the progeny. Further research is also required to better understand the link between abnormally high rectal temperatures at conception and the overall size of female progeny.

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Chapter 6

Ovine Artificial Insemination in the Maghreb Region: Present Status and Future Prospects

Moufida Atigui and Mohamed Chniter

Abstract

Artificial insemination (AI) plays a key role in the genetic improvement of farm animals. Although it is widely used for cattle in the Maghreb region, it is scarcely applied in sheep at farm level. This is not only due to low fertility and irregular results that range between 30 to less than 76% for both cervical AI with fresh semen and laparoscopic insemination with frozen semen in most of studied breeds and also because of low results related to conditioning of fresh, chilled and frozen rams' semen. An appropriately literature analysis was conducted to highlight the importance of sheep breeding in the Maghreb region particularly in Morocco, Algeria and Tunisia and to assess the efficiency of AI for Magrebin ovine breeds, the results related to different semen conditioning techniques and different AI procedures. The main factors affecting AI results are also presented. Finally, this chapter presents different strategies to improve AI efficiency at farm level in the future and the challenges to extrapolate experimental AI techniques to field conditions at a large scale.

Keywords: semen preservation, cervical insemination, laparoscopy, sheep

1. Introduction

Sheep farming is of great economic, social and environmental interest in all countries with a Mediterranean climate [1]. It remains an important activity in the southern Mediterranean countries particularly in Morocco, Algeria and Tunisia considering its adaptation to the majority of the countries' agro-ecosystems, which is due to the hardiness of the dominant breeds and to the flexibility of production systems in relation to socio-economic and land contexts [2–8]. Yet, breeding techniques at farm level are till nowadays basic and traditional based on pasture, which is subjected to the current issue of global warming causing severe rangeland degradation [5, 9]. This leads to substantial limited productive capacity of sheep characterized by a low annual productivity rate ranging between 0.66 and 1.24 lambs for most breeds in the Maghreb region [3, 4, 7] added to a relatively low carcass weight (about 15 kg) [10, 11] and low survival rate [7] causing a lack of red meat production.

In this framework, artificial insemination (AI) offers a powerful tool to develop ovine sector through speeding up selection programs and spreading the genetic progress. Thus, improving flocks productivity became a national objective in the Maghreb countries where several enhancing breeding programs have been initiated in order to remedy these problems starting with improving the control of reproduction and creating national centers for ovine using AI. Ovine AI offers enormous opportunities to support the sector development, by accelerating the programs of selection and dissemination of genetic progress. AI allows out-of-season reproduction and therefore milk or lamb productions that are better distributed throughout the year in response to the needs of the market. In addition, AI allows breeders to have access to the best mated male for herd renewal while limiting health risks. Furthermore, AI permits the multiplication of genotypes and limiting applied consanguinity, without multiplying the number of progenitor in the herd [12].

In recent years, continued improvements of this method in bovine, caprine and poultry coupled with a growing demand for the application of AI at farm level, as the numerous benefits it offers, are being increasingly recognized. Yet, ovine AI has progressed rather slowly in terms of breed improvement in comparison with the aforementioned species [13, 14]. The earliest documentation on a large scale ovine AI has been reported in Russia by Miovanov in 1938 [13] than spread to China and central Europe. It was not until the 80′s that the first reports of sheep cervical AI that was documented in the Maghreb region by Khaldi and Farid in 1981 in Tunisia [15] and Manar in 1987 in Morocco [16]. Later in 1992, that was the first documented laparoscopic insemination of French breed ewes in Morocco [17]. Ever since, ovine IA has gained researchers′ interest and several works have been developed since in order to investigate factors influencing IA results in Maghrebin sheep breeds and to improve fertility rate of inseminated ewes.

According to this context, our work aims to highlight the actual situation of assisted reproduction in sheep with a special emphasis on rams′ semen collection and preservation and AI in the Maghreb region. We will first address the importance of ovine farming and its limits in this region. Then, we will review the current status of AI in sheep particularly at farm level. Finally, we will focus on future consideration to enhance assisted reproduction and to discuss how to evaluate the applicability of ovine AI at farm level in the Maghreb region. Electronic databases (Elsevier, PubMed, and Web of Science) along with some official reports and thesis documents were consulted for an appropriate literature review. A total of 55 suitable references were considered for this chapter from 1981 till now.

2. Overview of sheep farming in the Maghreb region

Sheep farming in the Maghreb region is well developed mainly due to its flexibility and hardiness of the dominant breeds as well as spatial complementarities to agricultural production [2–8, 18]. It closely depends on the climatic conditions of the year as it is based on traditional farming systems related to pasture availability.

2.1 Place of sheep breeding in the Maghreb countries

For the whole Maghreb region, the total number of sheep increased from 23 million during the 1960s to nearly 30 million in 1970s and reached 34.9 million in 1980s to stabilize around 37 million during the 1990s. The most important increase in ovine flocks has been registered from 2005 to 2019. The total number of sheep in the Maghreb region reached more than 57 million by 2019 [19]. This rapid increase in the herd, the strongest in Algeria followed by Morocco (**Figure 1**), seems to have been favored by the short-term public efforts during the droughts and the distributions of barley and fodder to resist the disastrous damages of drought and climate change on pasture [20]. In Tunisia, the evolution of the herd was fluctuating before the sixties indicating a close dependence of sheep farming on climatic conditions.

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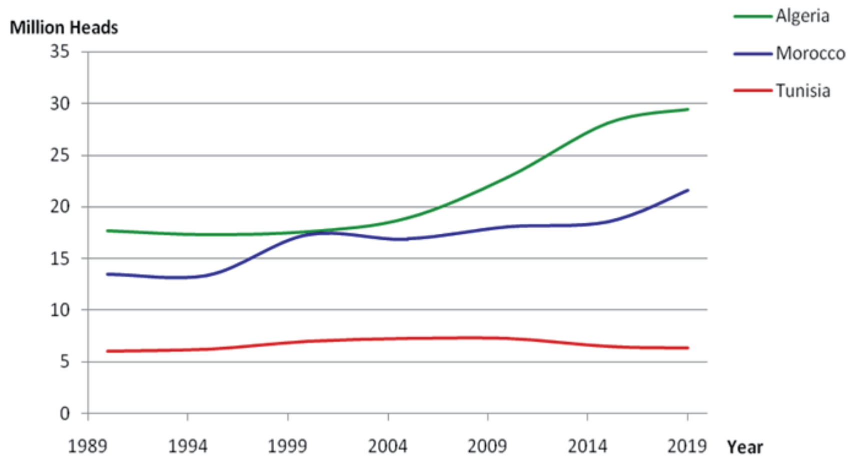

Figure 1.
Evolution of sheep stocks in the Maghreb countries (million heads).

Then through public safeguard campaigns and the subsidy for concentrated feeds, the sheep flocks have stabilized since the late eighties around 6 million head [4, 5]. The main objective of the public authorities was to increase sheep stocks and consequently to increase the production of meat for which these countries are in deficit.

Sheep farming is mainly intended for meat production in the Maghreb region, and most breeds were not selected for dairy traits, except for Sicilo-Sarde in Tunisia [21, 22]. It contributes significantly to the value of agricultural production in all Maghreb countries and insures a major part of self-sufficiency in meat consumption. For instance, ovine meat contributed with up to 48% in the total production of red meats in Tunisia estimated at 120,000 tons [4]. In Morocco, ovine stock ensures a meat production of around 130,000 tons of carcass equivalent yearly [23]. Likewise, according to official statistics of the ministry of Agriculture and Rural Development in 2017, Algeria has 26 million head of sheep and produces 325,000 tons of sheep meat, which ranked the country 5th in the world in terms of sheep meat production [8].

2.2 Characteristics of the main ovine breeds in the Maghreb region

The Maghreb region is characterized by different climatic zones from the Mediterranean coast to the oases of the Sahara. These diversified ecological conditions and climate types offered an extraordinary diversity of indigenous sheep breeds well adapted to their respective environments [24]. Except for Sicilo-Sarde breed in northern Tunisia, all sheep breeds in the Maghreb region were selected for meat and wool remains the next desirable product. Due to their proximity and commune history of the region's people, genetic flow between all Maghrebin breeds has shaped a rich livestock heritage [24, 25]. The Maghrebin sheep stock consists of several indigenous breeds with particular transboundary breeds (i.e., Algerian Hamra also called Beni-Guil in Morocco, D'Man and Ouled-Djellal). In this section, we present the main Maghrebin breeds that have been reported in the literature to receive genetic breeding programs and particularly artificially inseminated (**Table 1**).

The Algerian sheep population consists of nine breeds (Ouled-Djellal, D'man, Hamra, Rembi, Taâdmit, Sidaoun, Tazegzawt, Berbere and Barbarine), strongly adapted to harsh environmental conditions [26]. Some other non-official breeds were also reported originally introduced from Morocco and sub-Saharan Africa like Moroccan Srandi ou Sardi and Ifilene [27]. Due to the increasing farmers'

Main Breeds	Origin and current population	Description
	**Ouled Djellal** breed is the most important Algerian breed with over 11 million heads; it represents 63% of the Algerian sheep population.	The main purpose for meat production with a maximum adult weight of 80 kg for male and 60 kg for female.
	**Hamra** (also called Béni Guil in Morocco) is an indigenous breed from Algeria. This breed decreased from 3.2 million head in the 90s to less than 500000 heads in the last few years following the massive increase of Ouled Djellal breed.	This breed is reared for meat production. The adult weight is about 70 kg for male and 40 kg for female, with well adaptation characteristics for local pasture resources.
	**Berber** breed is the second main sheep in Algeria. It represents about 25% of Algerian herd with 4.5 million heads. This is probably the oldest breed in Algeria.	It is a small sheep with the values of 65 cm and 45 kg for male and 60 cm and 35 kg for female, respectively, for heights and weights.
	**Rembi** breed is an indigenous Algerian breed that represents about 11% of the Algerian herd.	The Rembi breed is considered to be the heaviest Algerian sheep with adult weights of around 90 kg for male and 60 kg for female.
	**Sardi** is an indigenous Moroccan breed. It occupies the poor rangelands of the western highlands of Morocco. It is estimated at to count 750 000 female units.	This is an excellent meat breed with an adult weight ranging from 70 to 100 kg for male and 45 à 60 kg for female.
	**Timahdite** is one of the main local Moroccan breeds with 1500000 female units and 11% of total national flock. It is located in the Middle Atlas region and well appreciated for its good conformation, carcass yield and quality of both meat and skin.	This breed is reared for meat production with an adult weight ranging between 60 to 80 kg for male and 45 to 55 kg for female.
	**Boujaâd** is one of the main five indigenous rustic breeds of Morocco. It counts for 260 000 heads, representing about 1.4% of the Moroccan ovine flock.	The Boujaâd breed is considered medium to large in size with the adult weight reaching 75 to 80 kg for the male and 45 to 60 kg for the female.

Main Breeds	Origin and current population	Description
	**D'man** breed is a Moroccan sheep well adapted to oasis ecosystem in Morocco, Algeria and Tunisia. In Morocco, it is estimated to 200 000 heads, 34 200 heads in Algeria and about 20 000 in Tunisia.	This is the most important prolific breed in north Africa. With a precocious puberty, continuous sexual activity and high prolificacy, D'man breed is very appreciated by oasis farmers; however, these animals are not resistant to harsh climate and poor pasture.
	The main meat sheep breed in Tunisia is the "**Barbarine.**" With two dominant strains, the Black and the Red Heads, it represents 64% of the total sheep herd of the country.	The **Barbarine** sheep is an indigenous breed known for its adaptation to the harsh climate conditions. This breed is easily recognizable by its large fat tail. The adult weight reaches 70 kg for male and 40 to 50 kg for female.
	**Queue Fine de l'Ouest** is originated from Algerian Ouled Djellal breed and occupies the mountains of the western Tunisia. It represents about 32% of total sheep flock in Tunisia.	This breed presents the similar characteristics compared to its Algerian origin breed. It is used for meat production purposes. The adult male could reach 80 kg and the female about 55 kg.
	**Noire de Thibar** is a Tunisian breed originated from many crosses between the Queue Fine de l'Ouest and the Black Merino of Arles. This breed represents about 2% of Tunisian sheep stock.	This breed was mainly selected for meat and wool. The adult weight is about 70 to 80 kg for male and 65 kg for female.
	**Sicilo-Sarde** is the only dairy breed in the Maghreb region. It is mainly located in northern and north western of Tunisia. With 83 000 female units, it represents about 0.5% of the national flock.	It is a light breed compared to meat breeds. The adult weight is about 35 to 70 kg for male and 25 to 45 kg for female with a dairy production of 0.7 l/ day and lactation period of 120 days.

Table 1.
Main sheep breeds in the Maghreb region.

preference to a single breed, Ouled-Djellal currently accounts for more than 63% of the Algerian sheep population. According to Mason [28], Moroccan sheep population is composed of some twenty different breeds well adapted to their variant ecosystems and tolerant to harsh climates. Currently, the most important breeds are Sardi, Timahdite, Béni Guil (also called Hamra in Algeria), D'man and Boujaâd. These breeds were phenotypically characterized and their breed standards were established since the beginning of 1980s [29]. The Tunisian sheep breeding sector is largely dominated by the indigenous fat tailed Barbarine with two different strains black headed and red headed Barbarine breed (64%), while the remaining thin tail breeds are "Queue Fine de l'Ouest" (30%), Noire de Thibar (2%) and Sicilo-Sarde

(0.5%). The main exogenous sheep breed found in Tunisia is the Moroccan prolific D'man breed, which represents about 0.25% of the total sheep population in Tunisia [30].

Despite the great genetic diversity, sheep productivity remains insufficient in the Maghreb countries. As a whole, it would be only 12 kg of lamb at weaning per ewe per year with 0.66 to 1.24 lamb/ewe/year in Morocco [3] and about 12.8 kg of lamb per ewe per year with 1.13 lamb/ewe/year in Algeria [7]. Similarly, the productivity of most Tunisian breeds was estimated about 0.8 weaned lambs per ewe per year and about 14 kg of lamb at weaning per ewe per year [4, 31] because of the low performance of the ewes and lambs. Low fertility, prolificacy, and high neonatal mortality are reported for most local breeds under extensive management system coupled with insufficient mastery of breeding techniques in terms of genetics, feeding and reproduction. Along with improving management's techniques and feeding conditions, researchers have recommended adoption of reproductive biotechnologies to improve the performance of these indigenous breeds and disseminate genetic progress [32]. Thus, several studies have been conducted to meet this need. In the following part of this chapter, we will review the most relevant works carried out related to reproductive biotechnology and AI in Maghreb ovine breeds with a particular emphasis on most important results at farm level.

3. Current state of ovine AI in the Maghreb region

The first documented studies on AI of ovine species in the Maghreb countries were reported during the 1980's following the establishment of artificial insemination centers by public authorities. Since its creation in 1975, the sheep breeding program in Tunisia has been managed by the Office of Livestock and Pasture (OEP). This program aimed to allow the dissemination of improved genes acquired by the herds controlled in sheep farms in different regions [33]. Sheep semen collection, control and conditioning are provided by the services of the Genetic Improvement Direction (DAG) of the OEP-trained pure local breed rams of the center (**Figure 2**). In Morocco, two artificial insemination centers (Fouarat and Aïn Jemaa) exist providing ovine AI services. Since the 90s, the Ministry of Agriculture has set up a laboratory for the semen storage of small ruminants at Aïn Jemaa Center. The goals assigned to this center were to produce and preserve ram semen deriving from five local breeds and several imported breeds (Ile de France, Merino and Lacaune) and the assessment of fertility of frozen semen [16]. It was only later (2006–2011) that the creation of three regional Centers of Ovine Artificial Insemination (COAI) in Algeria has led to

Figure 2.
Trained rams for semen collection a: Fat-tailed Barbarine b: Noire de Thibar (DAG, Sidi Thabet, Tunisia).

the introduction of this technique in sheep and its diffusion lately at national level [34]. Even though the creation of these centers had enhanced research on AI of local ovine breeds, the use of AI at farm level is till nowadays very limited and applied on few thousands ewes per year with little success.

3.1 Semen collection and preservation

One of the most limiting factors of the large scale use of AI in ovine selection programs is the difficulty of ram's semen preservation and cryoscopy. Thus, the use of fresh semen in trans-cervical insemination is the most common practice. For this reason, numerous studies have been recently performed with the goal of optimizing sperm cryopreservation protocols in this specie [35, 36]. However, there is paucity in studies about sperm collection procedure in Maghrebin local breeds. Semen collection from large numbers of untrained rams makes AI with fresh sperm at farm level difficult to perform. Thus, AI diffusion on a large scale relies on developing simple procedures to collect semen from untrained rams. Semen can be collected from live animals by artificial vagina (AV) or electrical stimulation (EE) [35]. Semen collection with an AV simulates natural conditions, but usually requires a preliminary training period of rams [35], whereas obtaining semen from a large number of rams, EE could be a useful and faster procedure [13]. However, most field trials conducted in Maghreb region were only performed with AV semen collection techniques (**Figure 3**) after 2-week period of rams training to ejaculate in AV [36, 37].

After collection, sperm must be diluted and cooled slowly but progressively from collection temperature (+32°C) to storage temperature (+15°C or + 5°C) in order to slow down the basal metabolism of spermatozoa from ejaculation until AI. Different extenders were used during liquid and frozen storage to improve sperm motility, viability and functional integrity of ram sperm membranes and ultimately success rate of consequent AI. In a previous work [32], different extenders were tested during liquid (15°C) and cryoscopy conservation of ram sperm. The use of

Figure 3.
Semen collection with an artificial vagina in the Tunisian " Noire de Thibar " ewe.

skimmed milk with sulfamid and antibiotics during liquid storage gave satisfactory results as sperm motility score ranged between 3.1 and 4.0 and sperm viability ranged between 52 and 71% during the mating season. These authors also tested the effect of two extenders (skimmed milk with egg yolk *vs.* Tris with egg yolk, citric acid and fructose) during frozen conservation. They used glycerol as cryoprotectant and antibiotics for both extenders. The freezing procedure was evaluated. Automated cryoscopy led to satisfactory post-thawed sperm quality with both extenders (over 3.1 motility score and 44% viable spermatozoa) recommended for intra-uterine insemination. However, manual cryoscopy caused severe damages of the spermatozoa and gave very low sperm motility and viability. Recent study [38] performed using four extenders: two based on egg yolk (egg yolk Tris and Tryladil), one based on milk (skimmed milk or Colas extender (use in equilibration and freezing)) and one to soy lecithin (Andromed) showed that the skimmed milk presented most advantageous in the preservation of the semen at 5° C. While diluents containing egg yolk have best preserved semen quality of ram INRA180 breed during the freezing procedure, it was found that ram effect was a significant factor in sperm storage in this study and it was found that sperm from ram number 2 showed the better resistance to storage, either in liquid or in frozen state [38].

To reduce the oxidative stress during storage process, several extenders and protective components have been tested with a particular emphasis on locally produced antioxidant agents in some plant extracts. Recently, in [39–41] it has been shown that the addition of argan oil and cactus seed oil with small amounts to Tris egg yolk/skim milk extenders increased the total sperm motility, progressive motility, viability and membrane integrity, and decreased the spontaneous and induced lipid peroxidation and DNA fragmentation in ram semen at 15 and 5°C temperatures. Similar effects were reported when 1% of *Opuntia ficus-indica* extract was added to extenders such as Tris or milk during liquid storage up to 72 h of storage [41].

3.2 Estrus synchronization and insemination timing

In sheep, most AIs are practiced with fresh semen on induced estrus within a few hours after the semen collection (optimum: 5 hours-maximum: 10 hours). AI efficiency is closely related to estrus induction and synchronization procedure.

Several synchronization techniques were tested for local breeds in the Maghreb region over the years. The most commune estrus synchronization procedure is based on the use of vaginal devices (sponges) impregnated with 30–40 mg of fluorogestone acetate progesterone implants for 14 days and equine Chorionic Gonadotropin (eCG) intra-muscular injection on removal day (**Figures 4** and **5**) [32, 34, 38, 42, 43].

Two synchronization treatments were tested for different Moroccan sheep breeds [44] using progesterone implant coupled with eCG or prostaglandin analog injection. Lambing rate of D'man ewes was 34.9 and 21.7% (respectively for ewes treated with PGF2α and progesterone), while this rate was 39.1 and 13%

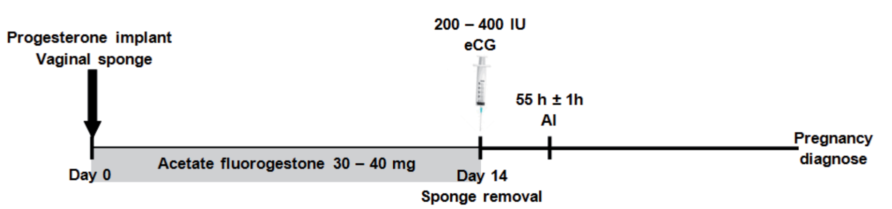

Figure 4.
Simplified estrus synchronization protocol for ewes.

Figure 5.
Intravaginal sponge insertion and PMSG injection in the Tunisian Barbarine ewe.

respectively for ewes treated with PGF2α and progesterone for Timahdite breed. A second trial focused on eCG dose (250 IU *vs.* 500 IU) in D'man and Sardi ewes, and the results showed a very low fertility after AI, from 10 to 40 in D'man and 12 to 28.5 in Sardi respectively for 250 and 500 IU.

Recently, the effect of eCG doses on fertility parameters' of Moroccan Boujaâd ewes were tested [45] and the use of 300 IU of eCG after 14 days of progesterone vaginal sponge insertion was recommended. With 400 IU, ewes had significantly higher prolificacy associated with higher neonatal death. On the other hand, eCG treatment has been associated with lower fertility rates on ewe′s consecutive cycles. The use of ram effect coupled with progesterone treatment instead of eCG injection in Barbarine ewes was also tested [43]. Results showed that substituting eCG treatment by the ram effect as synchronization treatment prior to artificial insemination could lead to satisfactory lambing rates.

Most reviewed works recommended performing cervical AI after 55 ± 1 hour after progesterone sponge removal using fresh or cooled semen [32, 34, 38, 42, 45] giving satisfactory results going up to 100% of synchronized ewes and pregnancy rate varying between 52 and 88%. Earlier studies tested performing AI after 60 h of progesterone implant removal in D′Man and Timahdite breeds. At this timing, the fertility rate was low for both tested breeds with 21.7% and 13% respectively for D′Man and Timahdite ewes. Moreover, it has been shown that cervical insemination of Barbarine ewes after 55, 56 and 57 h after hormonal treatment and progesterone sponge removal gave satisfactory results with respectively 59, 48.6 and 52% fertility rates [42]. However, when AI was delayed to 58 and 60 h after hormonal treatment, fertility rate dropped to 25 and 26.5%, respectively. Thus, it was recommended that large flocks should be divided into groups of 25 ewes in order to prevent time shifts during the procedure and prolonged the interval between hormonal treatment and AI application.

3.3 Advances in ovine AI in the Maghreb region

In the Maghreb region, ovine AI is till nowadays limited to experimental centers, and AI at farm level is not yet extended. In Tunisia, few thousand ewes are yearly inseminated as part of DGA activities to limit the effect of consanguinity in small pure breed herds, particularly Sicilo-Sarde and Noire de Thibar [46]. Thus, most of the presented data in this review remain experimental. Using fresh or cooled ram

Figure 6.
Cervical AI in the Tunisian "Noire de Thibar" ewe.

semen, intra-cervical (**Figure 6**) deposition of semen techniques results in acceptable fertility rates. However, using frozen-thawed semen, at present only intrauterine insemination gives acceptable pregnancy rates that remain difficult to achieve and to disseminate at large scale because of its cost and complexity.

3.3.1 Cervical insemination

This section summarizes the main findings in cervical insemination in the Maghreb ovine breeds. The conception rate to AI is calculated as the proportion of pregnant ewes detected by ultrasound scan at early stage of pregnancy or lambing ewes from inseminated ones. Results varied widely depending on the conditions and experiment protocol. In many studies, the ewe's breed has been found to have a strong effect on the pregnancy rate after AI. In an industrial breed crossing trial, the Sardi, Timahdite and Boujaâd Moroccan local ewes were crossed with rams of Ile de France, Merinos and Lacaune [47]. Cervical insemination was performed at 56 h after the sponge removal with fresh cooled (15°C) semen of 1.6×10^9 spz/ml concentration. Results showed the superiority of Sardi breed crossed with Merinos compared to the others with fertility rate 90.48% and prolificacy of 136%, while fertility rate ranged between 42.31 and 76% for Timahdit and Boujaâd breeds crossed with Ile de France, Merinos and Lacaune rams. The male may greatly influence fertility results after cervical AI. Variation in fertility of ram ejaculates exists independently of the sperm quality and after cervical inseminations with fresh semen [47].

A significant ram's age effect on semen quality in Algerian Ouled Djellal breed was reported [48]. The concentration and the mass motility were significantly higher in adult males. As expected, adult rams had significantly higher fertility and prolificacy (74.88 and 161.87%, respectively) compared to young rams (50.08 and 120.91%, respectively). However, the age of the female did not affect their fertility. They also reported that season had a highly significant influence on the ejaculate volume but not on the concentration and mass motility of spermatozoa. In a Tunisian study [38], fertility rate of the Barbarine ewes ranged between 32 and

41% with a significant effect of animal management was reported. Similarly, fertility rates ranged between 38 and 73% and prolificacy from 1.03 to 1.24 in the same breed with a great flock effect indicating the importance of body condition and nutritional background of animals to improve success rate of AI have been reported [43].

A study on AI at farm level carried out during spring mating following induced estrus of the four main indigenous Tunisian ovine breeds: Sicilo-Sarde (SS), Noire de Thibar (NT), Queue Fine de l'Ouest (QFO) and black head (BTN) and red head (BTR) Barbarine [46] reviled that the fertility of ewes inseminated out-of-season varied from 32 to 74% with an average of 47.56 ± 9.94%. The use of chilled semen (5°C) significantly ($p < 0.01$) reduced the success rate of AI with 43.76 ± 7.56% versus 55.95% ± 9.56% using the fresh semen. The superiority of the SS breed over the Tunisian meat breeds was perceived. An important effect of breeding management was detected, showing the importance of preparing ewes before using AI [46]. In another field trial aiming to improve the productivity of Timahdite breed, the fertility results obtained were as high as 60% of lambing rate, while in a field study carried out on herds from the same region (Middle Atlas), the fertility rates were 60, 44 and 41.5% respectively at Irklaouen, Timahdite and Ain Leuh communes [16]. The great variation of AI results at experimental level and at farm level indicates the potential of this biotechnology on large scale and the possibility of disseminating this technique. However, much still to be done in order to get reproducible results and limits the effect of factors of variation.

3.3.2 Laparoscopic insemination

Laparoscopic intrauterine insemination (LAI) is up-to-date the only technique that guarantees adequate fertility with frozen-thawed semen. Although it is still performed on experimental level, it is particularly interesting choice to use sperm with high genetic value [32, 49] and/or when semen is imported [17, 32, 49] or post-thawing semen quality is poor [50]. At field level, several factors limit the diffusion of LAI starting with its complexity and the need for highly trained technicians and advanced equipment to perform it. This procedure is also very expensive and have other problems related to animal welfare [51]. LAI offers higher and more constant fertility rates than cervical AI. In the Maghreb region, a few LAI trials have been performed in order to improve genetic value of some local breed, particularly small group breeds with high consanguinity risk.

It has been reported the use of intrauterine inseminations between 2005 and 2007 with Sarde-frozen semen imported from Italy in order to overcome the scarcity of sires and to alleviate consanguinity hazards on the Sicilo-Sarde dairy breed in Tunisia [49]. A renewal of phenotypic variability was observed mainly at the level of the herds, which benefited the most from this crossing. These animals, of different genetic types, took advantage of the superiority of the Sardinian breed, which improved several criteria of production or conformation. Results of gene injection protocol showed that fertility, prolificacy and mortality rates ranged from 53 to 68%, 157 to 184% and from 5 to 11%, respectively. A similar experiment was conducted in Morocco to improve the genetic value of imported French breeds used for commercial industrial crossbreeding since the nineteenth century. The genetic value of these breeds has been compromised by high consanguinity, since the import of live animals is restricted, frozen semen was the ultimate alternative inseminated with laparoscopic technique. Results ranged between 38.5 and 75.5% for fertility and 126.7 and 168.2% of prolificacy depending on breed with the highest results registered in the Solognot breed [17]. The gestation rate of Noire de Thibar ewes inseminated with frozen-thawed semen of Brune Noire Suisse rams with LAI ranged between 52 and 81% [32].

Even though, LAI is still very limited in the Maghreb countries, it is considered a good way to enhance genetic value of rams particularly in insemination centers and could be a powerful tool to increase genetic selection pressure.

4. Future prospect in ovine AI

In the Maghreb region, ovine breeding is developing continuously particularly in Algeria and Morocco since small ruminants are better suited to their production systems and to their harsh climate than cattle. Thus, it is likely that there will be an upsurge in the use of AI in these species in the future, with an emphasis on improving production traits by the injection of superior genes. Introducing innovative solutions is increasingly adopted by livestock holders including acceptance of reproduction biotechnologies [52]. This would allow a large-scale diffusion of AI in the future. However, one of the greatest challenges against any genetic improvement program at national level *via* AI is the improvement of animal husbandry and management to ensure the success of such program. AI would offer little help in areas where basic husbandry skills are inadequate.

The creation of breeding centers for pregnant young ewes and rams is essential to meet the needs of sheep breeders and contribute to the genetic improvement of the herd particularly in the dairy Sicilo-Sarde breed [53], Noire de Thibar and most breeds with relatively reduced numbers. In Morocco, for the first time, a private AI center has been founded with an ambitious program but it is still not functioning as expected [16]. Currently, this center is focusing on many goat projects and capacity building reinforcement of sector stakeholder, while little is done or has to be done in sheep. Future projects will involve insemination of 2000 ewes in Boujaâd breed and should later be extended to Sardi breed.

4.1 The cost of artificial insemination

One of the most important challenges against AI diffusion at large scale in the Maghreb region is its cost. Along with improving fertility rate following AI, researcher should focus on reducing intervention cost. For instance, AI charge in bovine specie in Tunisia is estimated around 3 € for the first IA, 2.45 € for the second and 1.84 € for the third and over till successful insemination for the same cow using locally produced pure breed semen. At this cost, coupled with the value of the animal, bovine AI is very valued and applied in both dairy and meat cattle. Yet the cost is significantly higher when the breeder chooses the use of imported semen and/or sexed semen to inseminate his cows, the cost is usually accepted given the importance of the genetic value of the expected offspring. On the contrary, the ovine AI real cost remains higher with lower commercial value of the product. Coupled with the estrus synchronization treatment, AI of ewes would be very expensive. This leads to the farmers' refusal to practice this approach. The use of more natural technique such as ram effect could reduce direct charges of the technique, although natural techniques lead always to very variable results. Even though the ovine IA services provided by governmental centers of AI are until nowadays free of charges in Maghreb countries, they are still localized and offer very limited services since the use of frozen semen is yet to develop. Information about the real cost of ovine AI is not available in the Maghreb region and the study of the economic impact of this biotechnology is strongly recommended.

4.2 Sperm cryopreservation

Most studies presented in this review had a particular interest to the storage conditions at 15°C and 5°C to prolong the storage time to 8–24 h. The extended refrigeration period would reduce the dependence of the AI centers. However, the needed doses were high (around 10^9 spz/ml) [47, 48]; thus, the number of doses/ejaculate remains very low. The effect of cryconservation [37] and different cryprotectors with different extenders in liquid preservation have been studied succinctly [40–43, 45], and most studies have been performed *in vitro* conditions. Most results showed good sperm preservation in liquid up to 24 h yet further research is required to design a valid strategy for the preservation of liquid semen from rams in the medium term 48 to 72 h. The effect of cryopreservation and freezing on ovine sperm was evaluated. Three steps were tested including storage in the liquid state (5°C), equilibration with four different extenders (Tris-egg yolk, Colas (skimmed milk based extender), Tryladil and AndroMed®) and then freezing [37]. The results showed that the time of storage at 5° C, equilibration and freezing have negatively affected the sperm quality. The skimmed milk had the best results at 5°C for 48 h compared to other extenders, while Tris-egg yolk extender was the best to preserve semen quality of rams during the freezing procedure with 72% total spermatozoa motility. These experiments revealed promising results *in vitro* but further studies will be needed to evaluate the effect of cryopreservation on sperm′s fertility.

4.3 Challenge of sperm deposit site: transcervical intrauterine insemination, the technique to develop

The development of a non-surgical AI procedure that could be performed efficiently and repeatedly with constant results will have tremendous implication on selection programs and genetic progress of sheep. Deposit site of semen during AI in the ewe′s genital tract has direct repercussion on fertility rate. Cervical AI leads to relatively low fertility rates even when using fresh semen. The particular, highly complex structural arrangement of ewe's cervix prevents easy transcervical passage and intrauterine deposition using conventional AI catheters [54]. Since the 1970, efforts have been made in order to access the uterine lumen by the transcervical route, which would allow the use of frozen-thawed sperm [55]. The success of transcervical intrauterine insemination depends on several factors, including cervical dilatation, the design of the catheters and the used procedure. Several works had investigated all these aspects, but none of these have been tested on local Maghreb breeds. A lot have to be done in order to promote AI of the ovine specie around the world and particularly in the Maghreb region.

5. Conclusion

In summary, despite the importance and the continuous progress of the ovine sector in the Maghreb region, particularly in Algeria and Morocco, AI is not yet an operative tool for the ovine breeding development and selection. Fertility rate following AI is very fluctuant and remains low 30 to 76% in most cited literature depending on the breed, the technique and the use of fresh, chilled or frozen semen. The development of AI of sheep became crucial to enhance genetic progress of this specie and to preserve some indigenous breeds with particular rustic characteristics and well adapted to their harsh environment. Many of the published studies are conducted under experimental conditions with a low number of animals; thus, it is difficult to extrapolate their conclusions to field conditions at a large scale. The use of frozen-thawed semen along with a non-surgical technique, if mastered, could enhance and promote the use of AI at farm level and accelerate the genetic progress of ovine. The combined protocols (modified catheters plus dilator substances) could be the beginning of the solution for transcervical insemination, but the complexity of the technique, the time spent in cervical penetration and the side effects that it produces are key factors for the success and dissemination of the TCAI and should be optimized to achieve an efficient procedure.

Conflict of interest

The author declares no conflict of interest whatsoever.

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Chapter 7

Kendrapada Sheep: An Insight Into Productivity and Genetic Potential of this Prolific Breed

Lipsa Dash, Sukanta Kumar Sahoo, Feroz H. Rahman, Simphoni Mohanty, Prasanta Kumar Nanda, Debi Prasad Kund, Surya Narayan Mishra and Susanta Kumar Dash

Abstract

Kendrapada sheep of Odisha is a prolific, medium stature meat type breed. The Kendrapada sheep is the second prolific sheep of India after Garrole of West Bengal, which carries FecB mutation, responsible for prolificacy. The reproductive traits of this sheep is the major attribute where the ewe of this sheep comes to heat at around 10–11 months and drops its first lamb at around 15–16 months of age. The average lambing interval in these sheep is 8 months with gestation period of 150 days. The reproductive performance of these sheep is the uniqueness of this sheep population with more than 70% multiple births; 62.8% twinning, 2.3% triplet and 1% quadruplets. Thus research should be undertaken to conserve the valuable germplasm of Kendrapada sheep to improve the other breeds of India which are good in context of weight gain but lack prolificacy. As sheep are well adapted to diverse climatic conditions they can easily thrive on wide variety of grasses and crop residues thus fits well in zero input free grazing system of rearing by rural poor. However the potentiality of this Kendrapada sheep in terms of meat quality and prolificacy and resistance to diseases has been the simulating force to take up base line survey along with variety of trials to conserve this breed. Keeping the above mentioned points in mind the present study was carried out to highlight the baseline details of this neglected breed as it is one of the first review articles on Kendrapada sheep.

Keywords: Kendrapada, sheep, Fec B, fecundity, prolific, germplasm, Odisha

1. Introduction

India has diverse breeds of sheep (44 breeds) which were adapted to different agroclimatic zones of the country. Sheep plays an important role in the rural economy and is principally maintained by poorer section of the rural community providing them a source of livelihood. Most of the breeds amongst those give single births and only few of breeds give birth to twins and triplets. The name 'Kendrapada sheep' of Odisha is highly prolific and excellent medium stature meat type breed. The climate of native tract of Kendrapada sheep is hot and sub-humid to hot and humid in nature and is located in south east coastal plain agro climatic zone of Odisha, India. The average annual rainfall is around 1500 mm and average relative humidity ranges from 31.6 and 93.4 percent over the months during the year. Recently National Bureau of Animal Genetic Resources (NBAGR), Karnal has recognized it as a new sheep breed of India with accession number INDIA_SHEEP_1500_KENDRAPADA_14042. This breed of sheep is smaller in size weighing 18 kg–20 kg and thus due to small stature these are known as "deshi" or "Kuji mendha". The distribution of Kendrapada sheep mainly extends from Bhadrak district to Nimapara (Konark) town of Puri district of Odisha. However this breed of sheep is present in the area extended around 100 km along Bay of Bengal coast from Konark to Chandbali. The majority of pure animals are found in the surrounding villages of Kendrapada district of coastal Odisha. The Kendrapada sheep produces 62.8% twins, 2.3% triplets and some 1% quadruplets [1, 2]. Most of the Kendrapada sheep (73%) carried the *Fec B* mutation [3]. This sheep has been identified as second sheep breed in India, which carries *Fec* B gene mutation. High prolificacy is a very much sought trait and is a major factor influencing the profitability in sheep farming. The Kendrapada sheep have many good qualities like adaptability to low input system of management, tolerance to hot and humid climate, resistance to many diseases along with very high prolificacy rate. These sheep are popular for their longevity and longer reproductive life, compared to other breeds of sheep. Being very docile and endowed with flocking together characteristics these animals are never a headache for farmers and serve as ready cash in emergency. These animals have always proved to be stress free under harsh climatic conditions with high humidity and flood situations. These sheep are popular for good quality skin, manure and low fat mutton. Milk is not an important attribute of this breed as the quantity produced is too less to be fed to its own lambs. This breed of sheep is endowed with the resistance to tropical diseases and has been proving its worth under extensive system of management under hot and humid climatic conditions, contributing to the livelihood of resource poor farmers [4]. However the potentiality of Kendrapada sheep in context to body weight, meat quality, prolificacy and resistance to diseases has been the driving force for the farmers to take it up as an enterprise. Some important aspects pertaining its performance characters are discussed underneath in this review.

2. Phenotypic characteristics of Kendrapada sheep

Kendrapada sheep is a medium stature compact meat type docile animal with very coarse and little curly wool as body coat. The head, leg and lower abdomen are free from hair coat. The color of sheep is predominantly light brown and blackish brown while in some cases black coat color with white patch on head are also seen. In most of the light brown colored animals the head color is lighter than the body (**Figure 1**). In contrary in case of dark colored animals the head and neck is darker than the body. The color pattern of animals mostly depends on the color of ram used for breeding in that particular area. However dark coat color animals are preferred over light ones and fetches higher price in case of marketing. This sheep possess an even rump indicative of high fleshiness and meatiness. While in most cases the head is straight, ears are mostly medium, horizontal in position and little drooping. These animals have no wattles or beard. These animals possess short and thick tail with round udder and small teats in case of females. The eyes of this animal are prominent, glowing and light yellow in color wit eyelashes matching to head color ranging from light to black color. Neck is little long with respect to body size. The average size of head in adult male is 16.96 ± 0.08 cm while in females it is 16.79 ± 0.08 cm. Both

Figure 1.
Kendrapada sheep medium statured brown colored.

the sexes of this breed are polled, however, males at times have small button like and curly horns. Orientation of horns in this breed is backward and color of horns is always black [5]. Hooves of these animals are usually grayish black.

Body measurements (cm).

Body measurements	Male (avg)	Female (avg)
Chest girth	70.33 ± 0.18	68.46 ± 0.17
Body length	54.28 ± 0.15	52.8 ± 0.15
Height at withers	56.67 ± 0.16	54.08 ± 0.16

Body weight (Kg).

Weight at	Male (avg)	Female (avg)
Birth	1.69 ± 0.03	1.58 ± 0.02
Weaning/3 months	6.74 ± 0.04	6.46 ± 0.04
6 months	11.15 ± 0.07	10.86 ± 0.06
1 Year	18.65 ± 0.10	17.22 ± 0.09
1st lambing	—	20.24 ± 0.32
Adult weight	21.15 ± 0.07	20.25 ± 0.08

Findings about body weight at all stages of growth revealed sex dimorphism in Kendrapada sheep resulting in heavier males than females. The dressing yields of Kendrapada sheep on empty body weight basis ranged from 49.42 to 50.07% and the meat of this sheep slaughtered at 2 years of age is more tender and leaner compared to meat obtained from 3 years of age [6].

Carcass characters.

	Male (avg)	Female (avg)
Age at slaughter (months)	11.8	18.7
Weight at slaughter (Kg)	17.3	21.4
Carcass weight (Kg)	8.37	10.2
Dressing %	48.4	47.6

3. Management practices of Kendrapada sheep

Kendrapada sheep are reared in the native tract only under extensive range system without giving any feed supplementation. A few animals are reared in organized farms under semi- intensive system with proper housing only. All the sheep in the native tract are kept in almost nil input basis. These sheep are usually left loose in the morning and allowed to graze across grazing land, road side vegetations and harvested fields mostly along with cattle herd of the village throughout the day. In town area, these sheep move around the market near vegetable shops and restaurants in search of food, along with grazing in nearby field. Though habituated of grazing themselves, the flocks are escorted with the owner while grazing during cropping season (**Figure 2**). In most of the cases the sheep do come back voluntarily before evening to their shelter place. During post harvest period the sheep often go for grazing in the morning and come back to shed in the evening.

3.1. Housing

As seen during random survey in the district about 65% of sheep farmers do not provide any defined shed for their animals. A part of their dwelling space is

Figure 2.
Free grazing with zero input system of rearing.

thatched roof only which is utilized as a resting space for animals during rain and cold nights. So it can be concluded that most of the Kendrapada sheep are penned in open housing system (**Figure 3**). The sheds are kucha in nature with mud flooring and thatched roofs (**Figure 4**). Ventilation is of utmost importance to maintain a desirable interior temperature of 28 to 30°C. If the animals cannot get rid of heat because the surrounding temperature is too high (> 30°C), they eat less and therefore produce less. Roofing material was made of bamboo in some cases and earthen tiles in other cases which were cheap and practical as mentioned in **Table 1** which was a part of our survey. A study was conducted to compare the growth and disease status of sheep kept under mud floor housing system and slatted floor platform based housing system. It was concluded that the wooden slatted floor in sheep shelters in this coastal areas benefit in increasing performance of growing lambs and adults with respect to body weight gain at different ages. This platform based housing system effectively controlled the gastrointestinal parasitic load which pose a great economic burden to the marginal and small farmers. It was observed from the above study that the coccidial load in mud housing system increased considerably during second sampling i.e. month of June which is the season for onset of south west summer monsoon in the district somewhat similar to that of first sampling which was taken in the month of March. On the contrary, there was significant reduction of coccidial load in sheep housed under platform raised housing during second sampling (June) which proved that the elevated structure above ground level was helpful in decreasing the coccidial load in sheep during the peak time of incidence in the district. Moreover, similar increase was found again during third sampling taken during end of October where in the coastal districts of Odisha there is onset of North east winter monsoon. These scenarios pose better survival of the oocysts in the surrounding due to increased moisture and increased incidence of coccidiosis due to uptake of infection through faeco-oral route. Further, in the platform raised housing system, the animals after administration of anti-coccidial drugs, were unable to pick up the infected oocytes from dry slatted floors which in contrary gets absorbed in the mud type housing system. In most cases the sheep are penned along with cows as a resultant sanitary condition of these places is very poor

Figure 3.
Open housing system of Kendrapada sheep.

Figure 4.
Sheep houses with mud flooring and thatched roof.

Housing	Frequency (N = 120)	Percentage
Open space	61	50.83
Kutcha with straw roof	18	15
Kutcha with asbestos/Earthern tile roof	15	12.5
Keeping with other animals	26	21.66

Table 1.
Distribution of respondents according to housing.

leading to soiling of animals and thus increase in cases of parasitic infestation. In case of large flock size close enclosures of asbestos is provided to the animals.

3.2. Feeding of Kendrapada sheep

Kendrapada sheep depend solely on grazing. Supplementation of kitchen waste or little amount of leftover cooked human food is a practice with lactating ewes only. During grazing hours the animals use nearby water source for drinking purpose. The lambs are usually allowed to go with their mothers. In few cases those are retained near the house. During this period the old people and children of the house take care of the lambs and often feed the lambs with rice gruel and other kitchen waste. Even the kids of house help these lambs suckle from the mother. The ewe comes back to the lambs at regular intervals for suckling and then again goes out for grazing. As the Kuji or Kendrapada sheep are only maintained on free grazing lands, it is often seen that they face feed scarcity due to low forage yield especially during lean periods due to wide seasonal variations and higher stocking density of animals as they are penned in open sky closed enclosures. As a resultant there is decreased dry matter intake and nutrient utilization pattern in these Kendrapada sheep even to meet the maintenance requirements, preventing them to express their full production potential and thus affects the profitability of these small and marginal sheep rearing farmers. In order to address the issues of low growth rates and meat productivity of Kendrapada sheep a different feeding practice needs to be developed to improve the marketable weight and slaughter yields of sheep by effectively utilizing the locally available crop residues and agro industrial by-products as feed resources. Utilization of crop residues as animal feed is an alternative to overcome feed shortages for ruminant feeding in India [7]. More than 75% of Kendrapada sheep owners possess less than half hectare of cultivable land. Only 3.31% of the farmers rearing this sheep own more than a hectare land, reflecting poor resource profiling of Kendrapada sheep farmers in the native tract. The flock size ranges from 5 to 27 [4]. If supplementation of feed during lean period and at vital stages of reproductive life is done then better growth rate is achieved [8]. A low cost scientific input as concentrate supplementation at the rate of 1% of body weight to ewes during this critical stage is recommended to enhance their production performance, general condition as well as growth rate of lambs [9]. The inculcation of low cost concentrate feed I the feeding schedule of 3rd month pregnant ewes upto weaning of lambs shows a drastic increase of 0.59 g in case of lambs, 2 kgs increase in case of 3 months old lambs, 5 kgs increase in case of 6 months old sheep, 6 kgs increase in case of nine months old sheep and 7 kgs increase in 12 months old sheep (**Figure 5**). While it was also found that lamb mortality also decreased by 42% as more instance of twinning was there. Thus it depicts that feeding of concentrates play a major role in weight gain along with decrease of lamb mortality. The population dynamics of Kendrapada sheep showed a declined trend over the decades which may be attributed to shortening of grazing land and constraints in marketing of animals as most farmers still depend on middlemen for marketing.

3.3. Breeding

Farmers rearing Kendrapada sheep often own their breeding rams if the flock size is more than ten. Breeding activities are carried out mostly at grazing. Therefore the female gets natural service from available rams nearby and hence manage to lamb with an average lambing interval of around eight months. The males are castrated at the age of around three months leaving the healthiest counterpart as future breeding ram of the flock. Evn some lambs are left uncastrated for

Figure 5.
Weighing of sheep after demonstration on supplementary feeding of sheep.

future use in ceremonial purpose. Generally one breeding ram is seen in a flock of 10 to 25 sheep in the grazing field. It has been realized through survey that sheep rearing families live in specific villages and not in every village as seen in case of dairy farmers as there is caste differentiation and beliefs stating a particular caste does sheep rearing and all caste should do this job or else they will be debarred from the village. Thus these villages are situated away from main village and also from each other as a result in the present context these sheep are very much confined to certain pockets of the districts and due to regular crossbreeding for increasing the body weight gain of lambs this breed is on the verge of extinction. Moreover as seen in most other parts of the state both in case of sheep and goat farming due to use of same breeding rams inbreeding depression is pretty common. In case of Kendrapada sheep this is not common as the males does not get enough scope to pass on their progeny to nearby villages but exchange of some sacred males between the villages continue for breeding purpose. There is neither any policy nor facility for artificial insemination through either government or non government organizations. Further neither the farmers are aware nor are interested for any such activity.

4. Reproductive performance

The average reproductive performance of this breed is depicted in the **Table 2**. The ewe of this breed attains sexual maturity at around 8 months of age and does lambing at around 15 months of age. The average lambing interval in these sheep is 8 months with gestation period of 150 days. Unlike other sheep this breed is not a seasonal breeder and gives birth in all seasons of the year. However majority of lambing is seen in early winter. These sheep deliver easily but sometimes help of owner is required during lambing. Mostly these ewes lamb in the house itself as they are reluctant to go for grazing during the period of advanced pregnancy. The lambs stand on their own for suckling after birth often due to scarce feeding weak lambs are born as there are multiple births that need assistance to stand. The reproductive performance of this sheep is only one of its kinds and is a unique feature of this breed as due to presence of *Fec* B gene more than 70% of population gives multiple births, out of which 62.8% are twins, 2.3% triplets and some 1% quadruplets [1, 2]. *Fec* B is an autosomal dominant gene located on chromosome 6, responsible for increasing the ovulation rate and litter size in sheep [10, 11]. It follows simple Mendelian inheritance. It has been reported that the effect of Booroola allele (*Fec* BB) is additive

SL.No	Attributes	Average
1.	Age at first mating in males (days)	428.28 ± 3.21
2.	Age at first mating in females (days)	372.8 ± 1.24
3.	Age at first estrous (days)	352.13 ± 1.06
4.	Estrous cycle duration (days)	20.49 ± 0.03
5.	Age at first lambing (days)	521.85 ± 1.14
6.	Lambing interval (days)	236.42 ± 0.56
7.	Service period (days)	87.45 ± 0.24
8.	Litter size	1.75 ± 0.02
9.	Lifetime lamb production	17.89 ± 0.09

Table 2.
Reproduction performance of Kendrapada sheep.

Sl No	Lambing	% Single birth	% twinning	% triplets
1.	L1	52.38	47.62	0
2.	L2 to L4	22.44	70.51	7.05
3.	> L4	21.78	65.35	12.87
4.	Overall	29.77	62.21	8.03

Table 3.
Prolificacy of Kendrapada sheep with respect to parity.

for ovulation rate and each copy of the allele increases ovulation rate by about 1.6 and approximately one to two extra lamb in Booroola Merino [12, 13]. *FecB* or the Booroola is a dominant autosomal gene mutation with an additive effect on ovulation rate [14]. The genotype and gene frequency of *Fec* BBB carrier are higher in Kendrapada sheep than Garole [15]. Prolificacy of Kendrapada sheep with respect to parity is mentioned in **Table 3**. The discovery of *Fec B* mutation in Kendrapada sheep puts the breed at second position in India and sixth position in the world pertaining order of breeds known to carry the mutation (Booroola Merino or BM, Garole, Javanese TT, Hu and small tailed Han), which has large effect on litter size [3, 16]. The frequency of *Fec* B allele in this sheep sample was about 0.73 [3]. The introgression of *Fec* B allele in nonprolific breed with higher bodyweight can significantly increase the productivity of sheep industry and subsequently farmers will be benefitted. The Kendrapada sheep would be a better choice for this purpose since the bodyweight of this breed is higher than the Garole breed [15]. It has been observed that though these sheep lamb in all seasons highest percentage of estrus is recorded during the spring season.

5. Health status of Kendrapada sheep

Kendrapada sheep are adaptable to hot and humid tropical climate and are thus resistant to many diseases, poor food sources and heat stress. As most of the farmers are illiterate, poor, lack resources and are less aware about public services they often use indigenous knowledge and medicines to treat some of the major and minor diseases. Only in case of chronic diseases these farmers seek veterinary aid. Castration of young males is done by both local experts and veterinary personnel. The animals are periodically vaccinated against FMD, HS, PPR and Enterotoxemia under state vaccination policy to enhance their immunity. Often farmers are reluctant to go for FMD vaccination due to incidence of post vaccination inflammation attributed to use of adjuvants in these vaccines. The change of season plays a great role in manifestation of diseases. In rainy season the incidence of digestive disorders, parasitic and viral diseases are more as compared to other parts of the year. In winter, the sheep are mostly afflicted with worm infection, Foot and Mouth and Septicaemia diseases. Though kept together with other breeds of sheep this breed suffers less intensely than other breeds. In most of the viral diseases like Bluetongue, PPR and bacterial disease as ET the incubation period is less than 24 hrs. Antibiotics are recommended to check secondary bacterial infections. In case of this breed majority i.e. approximately 80% of deaths in lambs have been estimated due to non-infectious causes. Starvation, primarily from mismothering and behavior, nutritional and environmental stress, reproductive problems and predation are the major causes reported (pneumonia, acidosis etc..). Kendrapada district especially Subala village of Mahakalpada block witnessed a huge mortality

Sl. No	Disease/symptoms	Season			Overall (%)
		Summer (%)	Rainy (%)	Winter (%)	
1.	Digestive disorder	18.6	22.3	5.3	36.2
2.	Fever	2.2	23.6	6.2	32
3.	Pneumonia	—	2.8	1.6	4.4
4.	Parasite	24.5	52.2	17.3	94
5.	Skin disease	2.5	3.6	3.1	9.2
6.	Anorexia	6.8	6.3	7.2	20.3
7.	Ear/Eye Infection	1.4	2.7	0.6	4.7
8.	Viral diseases	1.2	17.2	4.6	23
9.	Blood protozoan diseases	7.6	5.2	5.2	18
10.	Miscellaneous	5.4	4.2	6.3	15.9

Table 4.
Season wise diseases and symptoms of Kendrapada breed.

of more than 60 sheep in between December 2016 and January 2017 due to gastrointestinal form of Pasteurellosis followed by secondary parasitic infestation of *Haemonchus contortus*. Since then vaccination of HS was mandatory and those farmers who were reluctant to vaccinate continuously vaccinated their flock from time to time. As per change of seasons the incidence of various diseases is depicted in **Table 4**. Various reproductive disorders are also seen in case of Kendrapada sheep which is attributed to deficiency of essential vitamins and minerals **Table 5**. These reproductive disorders also pose a great problem to these small and marginal farmers. Various deficiency diseases also play a pivotal role as predisposing factor for death of Kendrapada sheep as seen in case of young sheep grazing on flood -stricken pastures suffer serious depletion of reserves of minerals and vitamins. Copper and Cobalt: Characterized by anorexia and wasting. Anemia, diarrhea and unthriftiness occur in extreme cases. In such cases if treatment with Copper or cobalt sulphate is done then it causes rapid disappearance of the symptoms. Another such example is deficiency of Calcium, Phosphorous & Vit. D: The daily requirement of Ca, P & Vit. D for an adult sheep is about 2.5 gm, 1.5 gm and 300–500 units, respectively. Deficiency may result in rickets in lambs and osteomalacia in adults. Mineral supplementation in diet is essential to prevent this deficiency. Last but not the lease is deficiency of Vitamin A which occurs in sheep kept on dry feed without much access to green fodder. Symptoms include night blindness, corneal keratinization, ptyriasis, hoof defects, loss of weight and infertility. Congenital defects are

Sl. No	Type of problem	Disease incidence (%) n = 218
1.	Abortion	2.29
2.	Still birth	0.92
3.	Retention of placenta	0.46
4.	Repeat breeding	1.37
5.	Anestrous	0.53
6.	Dystokia	1.38

Table 5.
Incidence (%) of reproductive health problems of Kendrapada sheep.

common in the offspring of deficient dams. Thus farmers are encouraged to go for green fodder cultivation and also give access to green pastures to prevent recurring occurrence of this deficiency.

6. Marketing

Sale and purchase of these Kendrapada sheep is mostly done at home of the owner. Sale of Kendrapada sheep is also realized in weekly village level markets. Most of the meat production and marketing practices in the district is traditional. Well-integrated marketing system for meat and meat products is lacking in Odisha a glimpse of which is seen in case of marketing this breed. According to a survey conducted by us regarding marketing of this breed as mentioned in **Table 6** it pose problem amongst the local farmers. The main reason being monopoly of meat trader, lack of coordination between production and demand, too many middlemen in the trade which fetch low price to the innocent, shy sheep owner [17]. It is also observed that the mutton of Kendrapada sheep is a delicacy for biryani preparation amongst the hotel owners of the cities. Moreover in cities people choose a small stature dark skin coated animal for preparation of delicacies. Thus mutton is more preferred over chevon due to presence of more quantity of interstitial fat and once dressed people are unable to make out any difference between mutton and chevon so its seen mutton is more relished than chevon. But still these local farmers have to wait for various seasons and occasions in order to sell their mutton at a good price as mentioned in **Table 7** an output of our survey. Usually males are raised for marketing but adult rams are mostly used for cultural and asthetic puposes. Females are normally never sold until and unless there is some financial exigency. Stress sale or push sale of this sheep breed has never been recorded not even during flood and cyclonic conditions. Moreover there is no instance of marketing hide, skin, horn, milk and manure from these sheep. Thus keeping the problems of these local farmers this marketing part needs a lot of renovation as development of adequate market infrastructure with basic requirements which is a must for marketing. Secondly because of the unorganized nature of the sector local farmer is not getting good price and middlemen gets benefited. Thus there is a dire need to modernize the meat production and marketing system of Kendrapada sheep. The state government is keen to improve the marketing system so that the consumers would get the quality meat and meat products at reasonable prices. Thirdly along with the production and productivity increase marketing facilities shall be prioritized to compete the export markets and to increase the income then only this endangered breed will be prevented from being extinct and farmers will be encouraged to continue farming of this pure breed without crossbreeding.

Time of marketing	Always (%)	Sometimes (%)	Never (%)
After 10 month	25	42	33
After 1 year	46	43	11
At body wt. of 15 kg	52	36	12
At body wt. of 20 kg	56	38	6
At the time of necessity	62	24	14

Table 6.
Distribution of respondents according to marketing.

Period of selling	Always (%)	Sometimes (%)	Never (%)
No specific period	84	12	4
Festive season	6	35	59
Wedding season	10	47	43

Table 7.
Distribution of respondents according to marketing demand.

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Section 3

Improving Animal Health, Understanding Zoonoses

Chapter 8

The Role of Cryptosporidiosis in Sheep Welfare

María Uxúa Alonso Fresán and Alberto Barbabosa Pliego

Abstract

Welfare in animal production has been defined as the optimal mental and physiological state of the animals. It has been recently redefined according to animals' freedoms. As systems, individual sheep and herds are dynamic with constant interaction with each other and the environment. In this interaction, diseases play a fundamental role in welfare. Parasitism is common in sheep, and several management practices have been established to maintain the herds healthy. *Cryptosporidium* represents a special case, because it is a highly resistant environmental parasite, that can easily infect lambs, producing weakening diarrheas and even death. In this chapter, the role of cryptosporidiosis in sheep welfare and economic loss will be analyzed, as means of providing information on how to minimize and deal with the infection.

Keywords: *Cryptosporidium*, cryptosporidiosis, sheep, lamb, welfare, diarrhea, economic loss, prevention, control, treatment

1. Introduction

Animal welfare and health status in herds go hand in hand. When pathogens are present, disease may develop and will be reflected on decreased productivity. Parasites are pathogens which may be found in the environment as well as in the hosts, some of them as opportunists that can cause disease. Such is the case of *Cryptosporidium spp*., a ubiquitous parasite with worldwide distribution, which causes diarrhea in newborn lambs that can lead to death or self-limiting diarrheas in immunocompetent hosts. In this chapter, welfare and cryptosporidiosis is discussed in an attempt to provide information on how to prevent and control the disease.

2. Welfare generalities

According to the World Organization for Animal Health (OIE), animal health and welfare is defined as "the physical and mental state of an animal in relation to the conditions in which it lives and dies", and covers "the five freedoms": "1) freedom from hunger, malnutrition and thirst; 2) freedom from rear and anxiety: 3) freedom from heat stress or physical discomfort; 4) freedom from pain; and 5) freedom to express normal patterns of behaviour", [1]. These were developed by the UK Animal Welfare Council (FAWC) in 1979, after researching on farmed animals in intensive systems, [2].

Derived from these freedoms and based on [3], Codes of Best Practices for Welfare Establishments have been developed, such as the one from the Welsh Government [4], in which a series of issues are covered, in order to keep the animals healthy and productive. As an example, this one indicates not only how the animals should be managed, but also how staff and volunteers should be managed too. Regarding animal management, a conscientious record of animal admissions, behavior and assessment, housing and environment, cleaning and hygiene among others are defined. Animal health and disease are also included, as well as rehabilitation, rehoming of release, and transportation, all based on the corresponding legislation.

There is a close relationship between animal health and welfare. If they are optimal, they will promote high productivity and the reduction in the use of antimicrobials, as well as reduced risk for foodborne diseases to humans [5].

3. Welfare and disease

In this sense, the AWIN welfare assessment protocol for sheep [6], defines welfare indicators according to principles and criteria, in which good health is measured by the absence of disease, and according to this protocol and the objective of this chapter, it is indicated by fecal soiling. The European Food Safety Authority (EFSA) has identified gastroenteric disorders among the main welfare consequences in lambs [1]. Regarding gastroenteric disorders, diarrhea is defined as a "complex, multifactorial disease involving the animal, the environment, nutrition, and infectious agents" [7], in which *Cryptosporidium spp.* is among the most common. It is an apicomplexan protozoa that causes profuse diarrhea in neonatal lambs (4–9 days old), with low mortality, increasing concurrent infection and deficiencies in nutrition and husbandry. In well-fed animals, it often persists for 5–7 days, lessens and lambs recover. Diarrhea leads to dehydration, inappetence, abdominal pain and lethargy. Diarrhea is liquid and yellowish, varying from mild and self-limited to severe (when mixed with other pathogens) but relapse is quite common [8]. Cryptosporidiosis produces severe villous atrophy, caused by loss of enterocytes, with crypt hyperplasia by the replacement of epithelial cell loss. This occurs due to the cytotoxic effect of the parasite and apoptosis it causes, resulting in a malabsorptive diarrhea, with prostaglandin-mediated anion secretion [9].

Other pathogens might be present in diarrheas caused by Cryptosporidium spp., such as rotaviruses, *E. coli*, *Salmonella spp*. or coronaviruses. In this case, prognosis degenerates and clinical signs and treatment become complicated [10].

4. Species and life cycle

There are more than 38 species of Cryptosporidium, but only three main species are reported in small ruminants: *C. parvum*, *C. xiaoi* and *C. ubiquitum* [11]. *Cryptosporidium spp.* oocysts size ranges from 4 to 4.5 μm, with spherical to ovoid shape, and four sporozoites per oocyst. They can be identified through Ziehl-Neelsen stain, where oocysts are shown as bright pink round bodies. The transmission of the infection happens by direct ingestion of oocysts present in food and water. Once in the host, oocysts excyst in the gut and sporozoites are released, entering the intestinal epithelial cells through the brush border [12]. After excystation, sporozoites are found in the extracytoplasmatic

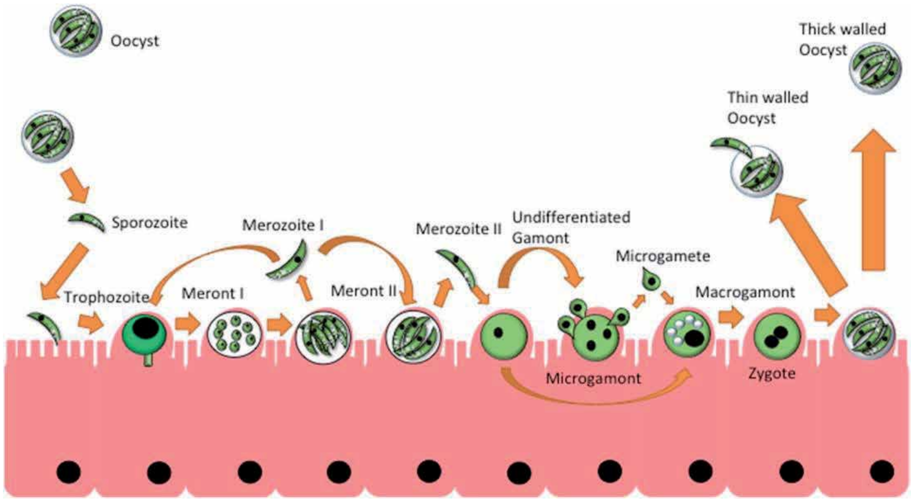

Figure 1.
Cryptosporidium spp. life cycle [14].

parasitophorus vacuole, where the parasite reproduces either asexually or by schizogony, leading to 8 merozoites within a type I meront. Merozoites are capable of invading neighboring epithelial cells and other sites of the intestine, where they either reproduce asexually forming thin-wall oocysts that cause autoinfection or a sexually forming type II meronts differentiating into microgametocytes and macrogametocytes, which will unite to form the zygote. This zygote will form 4 sporozoites in thick or thin-walled oocysts, by a process called sporogony. The ones with the thick wall are released to the environment through feces [13] (**Figure 1**). Up to $1X10^6$-$2X10^6$ oocysts/g of feces can be excreted by the host (which are immediately infectious) becoming a source of infection to susceptible lambs [15]. Oocysts can survive in water and in the environment several months, as soon as cool temperatures and suitable moisture exists, and can be easily transported through air and water [16].

5. Prevalence

Cryptosporidium was incidentally discovered by Tyzzer in 1907, but until 1978 oocyst identification in feces samples was confirmed through microscopy, making it the diagnostic method. Several stains have been proven, but the most common is modified Ziehl-Neelsen. Next came immunological tests which are more sensitive and specific for the detection of antigens, giving rise to immunofluorescent tests. These are specially used in water samples. Finally, genetic tools such as PCR were developed to identify the species [17, 18]. Nevertheless, microscopy using stains still remains as the simplest, cheapest and the most common way for detection.

Ever since it was first detected and confirmed as pathogen, there have been many studies regarding prevalence in sheep from different geographical regions, in which its presence may be attributed to either infectivity or the contamination of the environment [19]. In an attempt trying to explain the wide variation in prevalence, it is shown in tables according to Koeppen's climate classification (**Tables 1-5**).

Author	Year	Country	Detection test	Population	Prevalence (%)	Climate
[20]	1990	Guaiba District, Brasil	Z-N	10 lambs	20	Aw
[21]	1993	Trinidad and Tobago	Z-N	51 diarrheic lambs 31 healthy lambs	24.5 10	Am
[22]	1995	Western Malaysia	Z-N	25 lambs	36.0	Af
[23]	1996	Morogoro Region, Tanzania	Z-N	121 lambs	97.5	Aw
[24]	2001	Ibadan, Nigeria	Z-N		43.3	Aw
[25]	2003	Aba,Nigeria	Z-N	29 sheep	2.1	Am
[26]	2014	Papua New Guinea	PCR	276 adult sheep	2.2	Aw
[27]	2015	India	IF	20 (5 sheep/pool)	45	Aw
[28]	2017	Sinaloa, Mexico	Z-N	1144 lambs (1–90 days old)	41.58	As
[29]	2018	Northern Veracruz, Mexico	Kinyoun	210 healthy lambs	19.5	Aw

Af: Tropical wet; Am: Tropical monsoon; As: Tropical dry savanna; Aw: Tropical savanna.

Table 1.
Cryptosporidium spp. prevalences reported in climate a (tropical).

Author	Year	Country	Detection test	Population	Prevalence (%)	Climate
[30]	1994	Ismalia, Egypt	—	100 lambs	24	BWh
[31]	1998	Gharbia province, Egypt	—	52 s lamb	7.69	BWh
[32]	2002	Tehran, Iran		87 sheep	Lambs (less than a month old): 14.28 Ewes (3 years or more): 17.69	BSk
[33]	2002	Basrah, Iraq	Z-N	45 sheep	13.3	BWh
[34]	2002	Dakahlia Governorate, Egypt	Z-N	200 lambs	13.3	BWh
[35]	2002	Zaragoza, Spain	Z-N	344 lambs	59	BSk
[36]	2004	Sharkia and Dakahlyia Provinces, Egypt		470 lambs and kids (310 diarrheic y 160 healthy)	16.8 in diarrheic animals	BWh
[37]	2007	Aguascalientes, Mexico	Kinyoun	40 sheep	100	Bsh
[38]	2014	Kafr El Sheikh, Egypt	Z-N	45 lambs 75 sheep	4.4 1.3	BWh
[39]	2015	Lahore, Pakistan	Z-N	150 diarrheic and healthy lambs: 0–3 months 4–6 months 7–12 months 1 year	40 22.5 12.5 6.67	Bsh
[40]	2019	Yazd Province, Iran	PCR	192 slaughtered adult sheep	5.7	Bwk

BWh: Tropical and subtropical desert; Bsh: Mid-latitude steppe and desert; BSk: Tropical and subtropical steppe.

Table 2.
Cryptosporidium spp. prevalences reported in climate B (dry).

Author	Year	Country	Detection test	Population	Prevalence (%)	Climate
[41]	1990	V, VI and Metropolitan regions, Chile	Z-N	57 diarrheic lambs 114 healthy lambs	3.5 (diarrheic) 7.9 (healthy)	Csa/Csb
[42]	1990	Elazig, Turkey	—	267 lambs	12	Csa
[43]	1991	Lorestan, Iran	Z-N	215 healthy lambs	17.2	Csa
[44]	1991	Valdivia, Chile	Z-N	196 dead lambs (0–28 days of age)	7.7	Cfb
[45]	1991	Galicia, Spain	Safranin methylene blue and Köster stain	69 lambs (6 days-6 months of age)	1.45	Csb
[46]	1994	Larissa, Greece	Z-N	65 diarrheic lambs	4.61	Csa
[47]	1996	Castille and Leon, Spain	Z-N	183 diarrheic lambs	45	Csb
[48]	1999	China	—	3250 lambs	23.08	Cfa Cwa
[49]	2000	Izmir, Turkey	—	150 diarrheic lambs 50 healthy lambs	23.3 2	Csa
[50]	2000	Poznan, Poland	Z-N	205 lambs	10.1	Cfb
[51]	2001	Poland	Coproantigen	17 lambs	11.76	Cfb
[52]	2004	São Paolo, Brasil	Z-N	184 lambs in rainy season 179 lambs in dry season	55.4 17.3	Cfa
[53]	2004	Aydin Province, Turkey	Heine	67 diarrheic lambs 77 healthy lambs	79.1 18.2	Csa
[54]	2004	Guangdong, China	Fenol, auramine and Z-N	Sheep	21.7	Cwa
[55]	2005	São Paolo, Brasil	Auramine O and Z-N	20 sheep 20 lambs	26.7 31.9	Cfa

Author	Year	Country	Detection test	Population	Prevalence (%)	Climate
[56]	2005	Central Mexico	Z-N	1200 (559 lambs and 641 ewes)	General: 34.3 Lambs: 32.5 Ewes: 35.9	Cwb
[57]	2005	Konya, Turkey	Z-N	471 lambs (1–60 days of age)	2.97	Csa
[58]	2006	Hirta, St. Kilda, Scotland	Z-N	Lambs and sheep	2001–2028.6 2002–9.0 2003–2011.9	Csa
[59]	2006	Serbia	Z-N and Kinyoun	126 lambs (1–90 days of age)	42.1	Cfa
[60]	2007	Maryland, USA	IF	32 ewes 31 lambs	9.4 32.5	Cfa
[61]	2007	Galicia, Spain	IF	446 adult sheep	5.3	Csb
[62]	2007	Tunisia	PCR	89 sheep (healthy lambs and adults)	11.2	Csa
[63]	2007	Eastern England	FAT	80 asymptomatic lambs	9.7	Cfb
[64]	2008	Central Macedonia, Greece	Z-N	207 diarreic lambs 79 healthy lambs 237 healthy ewes	55.07 15.18 10.97	Csa
[65]	2008	East Flanders, Belgium	IF and PCR	137 lambs (1–10 weeks old)	13.1	Cfb
[66]	2009	Australia	PCR	477 pre-weaned sheep	24.5	Csb
[67]	2014	Crete, Greece	IF	425 lambs	5.1	Csa
[68]	2015	Jammu District, India	Z-N	55 diarheic lambs	45	Cfa
[69]	2016	Veracruz, Mexico	Z-N	80 sheep	70	Cfb

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Author	Year	Country	Detection test	Population	Prevalence (%)	Climate
[70]	2016	Lorestan,Iran	Z-N	345 sheep (lambs and adults, diarrheic and healthy)	5.8	Csa
[71]	2017	Poland	PCR	234 asymptomatic lambs	19.2	Cfb
[72]	2018	Algeria	PCR	62 lambs	14.5	Csa
[73]	2020	French Basque Country, France	Heine	Asymptomatic sheep: 79 lambs 72 ewes	1.3–77.8 1.4–50	Cfb
[74]	2020	Sardinia Provinces, Italy	Z-N	915 lambs (diarrheic and healthy)	10.1	Csa
[75]	2021	Kenya	Z-N	388 sheep	19.6	Csb

Cfa: Humid subtropical; Cfb: Marine West Coast; Csa: Warm summer Mediterranean; Csb: Hot summer Mediterranean; Cwa: Monsoon-influenced humid subtropical.

Table 3.
Cryptosporidium spp. prevalences reported in climate C (temperate).

Author	Year	Country	Detection test	Population	Prevalence (%)	Climate
[76]	1993	Ohio, U.S.A.	IF	9 newborn lambs (5–10 days of age) 23 lambs (2–3 weeks of age) 23 healthy ewes	100 78.3 17.4	Dfa/Dfb
[77]	1995	Hungary	Z-N	53 lambs	22.64	Dfb
[78]	2009	Kars, Turkey	Z-N	400 diarrheic lambs (up to one month old)	38.8	Dfb
[79]	2013	Iran	Z-N	231 diarrheic and healthy lambs	2.5	Dsa
[80]	2016	Qinghai, China	PCR	350 sheep	12.3	Dwc
[81]	2019	Ladahk, India	Z-N	37 sheep (0–5 years old, diarrheic and asymptomatic animals)	54.0	Dwc
[16]	2020	Azerbaijan	Z-N	1,823 sheep	34.17	Dfb

Dfa/Dfb Humid continental; Dfb Warm-summer humid continental; Dsa Hot summer continental; Dwc Monsoon-influenced subartic.

Table 4.
Cryptosporidium spp. prevalences reported in climate D (continental).

Author	Year	Country	Detection test	Population	Prevalence (%)	Climate
[82]	1997	Different regions in Canada	IF	89 sheep	24	Dfb Dfc Dsb Cfb
[83]	2013	Uttar Pradesh, Uttarakhand, Bihar, Karnataka and Kerala States, India	Z-N	55 lambs	1.8	Csa Cwa Aw Am
[84]	2014	Iran	Z-N	1749 asymptomatic sheep	11.3	BWh Bwk Csa BSk
[85]	2014	Australia	PCR	1182 lambs (12–29 weeks old)	16.9	Cfb Bsh Csa Csb Cfa BWh desert
[86]	2021	Iran	—	3901 sheep Metanalysis	9.9	BWh Bwk Csa BSk

Am: Tropical monsoon; Aw: Tropical wet savanna; Bsh: Mid-latitude steppe and desert; BSk: Cold semiarid; BWh: Tropical and subtropical desert; Bwk: Tropical and subtropical desert; Dfb: Warm-summer humid continental; Cfa: Humid subtropical; Cfb: Marine West Coast; Csa: Warm summer Mediterranean; Csb: Hot summer Mediterranean; Cwa: Monsoon-influenced humid subtropical; Dfc: Subartic; Dsb: Mediterranean-influenced warm-summer humid continental.

Table 5.
Cryptosporidium spp. prevalences reported in studies from countries in which several regions were sampled.

Results show that it can be found in all different climates. One important factor is the high resistance of the oocysts when shed to the environment. Whenever there are conditions in which the parasite can survive (protection from desiccation or avoidance of direct sunlight) it will be present, even in zones with low humidity [87]. As cryptosporidiosis is multifactorial, it is also very important to take into account the immune status of the host. Immunocompetency varies with age, therefore making lambs the most susceptible. When sheep are immunocompetent, they develop the disease with weakening diarrhea and excrete high loads of the parasite, but it is self-limiting. They remain as healthy carriers, still excreting infective oocysts to the environment. Therefore, it is also important to analyze the prevalence results according to the health status of the host. In some countries, such as Iran, where studies with different climates have been undertaken (**Table 5**), prevalence has maintained with almost no shifts through time (2014: 11.3%; 2021: 9.9%). Nevertheless, in this same country, in studies where samples were taken in specific zones (dry climate), results show ample variation (2002: 14.28 and 17.69%; 2019: 5.7%), in samples taken from sheep with different ages. In other cases such as Mexico, prevalence was reported in 2005 in a temperate region (34.3%), 2007 in a dry region (100%) and in 2017 (41.58%) and 2018 (19.5%) in a tropical region, where variation in prevalence is wide. India is another example of wide variation in results. In 2013 a prevalence of 1.8% was reported in several climate regions, in 2015, 45% (tropical and temperate climate) and in 2019, 54.05% in continental climate. The studies in Nigeria with only a difference of two years show a prevalence of 43.3% in 2001 and 2.1% in 2003 in tropical zones. Turkey reports in 2004 a prevalence of 79.1% and in 2005 of 2.97% in lambs with wide variation too in the temperate climate zone. With all these examples, it is evident that generalizations cannot be made, neither by country nor continent. These results only prove the parasite's worldwide distribution throughout different climate zones, ages and health status of sheep.

6. Economic loss

Economic loss is reflected not only in mortality, but in retarded growth rates, decreased feed conversion rate, poor carcass quality, veterinary assistance and increased costs due to extra care. Moreover, healthy sheep can shed oocysts, specially periparturient ewes, with the possibility of maintaining the infection within the flock [88] and contaminate the environment [73].

Cryptosporidium causes diarrheas in developing countries, and it has been found that in developed countries it has become a serious problem, due to the limited number of parasitic protozoa in their surveillance programmes, as well as being a neglected disease caused by high confidence in hygiene, municipal sanitization services and good agriculture and livestock practices [18].

The model GloWPa-Crypto was used in [89] and differences were found in oocyst load in extensive and intensive systems, in which intensive ones provided a higher load directly on land.

7. Prevention, control and treatment

Transmission of *Cryptosporidium spp.* is influenced by reservoirs and environmental characteristics. Oocysts are sensible to high temperature and desication. Direct sunlight for several hours entirely inactivates oocysts [90]. To prevent and protect lambs from cryptosporidiosis, colostrum is fundamental. Hygiene measures are very important to destroy the parasite and prevent its transmission in between animals and from the environment. Cleaning and disinfecting pens and buildings, the use of clean straw beds, avoiding high number of ewes in the parturition area and separating healthy from ill animals during diarrhea outbreaks, as well as an appropriate and in time administration of colostrum to lambs, aid in the prevention of cryptosporidial outbreaks and decreases the morbidity and mortality in sheep herds [91].

There are three main ways for treating cryptosporidiosis in farms: using drugs (most of them have been proven at laboratory level), fluid therapy and reducing the quantity of oocysts excreted to the environment [92].

There is no specific drug targeted against cryptosporidiosis, although more than 140 active principles have been tested *in vivo* and *in vitro* but none of them have been useful for eliminating cryptospodiosis from the infected animal. This can be explained because of its particular intracellular but extracytoplasmatic location in the intestine, making it resistant to antimicrobials as well as a difficult drug target. The first attempts to cure cryptosporidiosis were based on using the same drugs as the ones for genetically related pathogens (Apicomplexa) such as *Toxoplasma* and *Plasmodium*, but are not suitable against *Cryptosporidium* because of differences in its cell biology and biochemistry: it has no apicoplast organelle, neither citiric acid cycle nor cytochrome respiratory chain. Due to the fact that cryptosporidiosis has had a higher impact in underdeveloped countries, the strategy for treatment has been the use of existing medications [14].

Significant results have been found when using halofuginone lactate [93], which is the only one licensed treatment for cryptosporidiosis in calves, thought to interfere with the merozoite and sporozoite stages of *Cryptosporidium* and proven effective in the control of oocyst shedding [94]. It is an antiprotozoal drug for *Eimeria* and *Theileria*, derivative of quinazolinone [95], used both for prevention and treatment [96]. Other drugs that have also reduced the excreted number of oocysts [40] are: paramomycin, (an aminoglycoside broad-spectrum antibiotic, poorly absorbed in the gut, remaining active in the lumen [97]), metronidazole (a nitroimidazole used against giardiasis [95]), benzoxaborole (a synthetic boron-heterocyclic compound that inhibits essential enzymes, used an antimalarial) and occidiofungin (a broad-spectrum glycolipopeptide with antifungal activity) [98, 99]. Nitazoxanide (nitratiazole benzamide derivative, licensed in humans as treatment for cryptosporidiosis [95]), beta-cyclodextrin (a cyclic oligosaccharide made up of glucose residues [100], used as pharmaceutical excipient [101]) as well as colostrum preparations, probiotics and decoquinate (coccidiostat quinolone derivative [102]) have also been used [103]. Therefore, the following sanitary and breeding recommendations are essential: sectioning of age groups, assurance of sufficient colostrum supply and intake, isolation of sick animals from the healthy ones, avoiding over-population, cleanliness and dryness of the environment, disinfection of premises and daily cleaning of equipment [93].

As alternative treatments, experiments in mice using watery and alcoholic extracts from *Curcuma longa* and *Coriandrum sativum* have been effective in reducing the number of excysted oocysts [104]. *Peganum harmala*, *Artemisea herb-alba* and *Olea europea* have shown similar results [105].

The most important measure to lessen the clinical signs of cryptosporidiosis is oral or intravenous fluid therapy. To decrease the spread of the disease, it is imperative to avoid oocyst shedding to the environment. For decontamination of surfaces, over 35 disinfectants have been tested, but only 5 are effective: 50% ammonia, 3% hydrogen peroxide, 10% formalin, Exspor and Oo-cide. Formaldehyde or ammonia gas used for steam heat sterilization and fumigation are also recommended [103]. UV radiation and ethylene oxide have been reported to be effective [106].

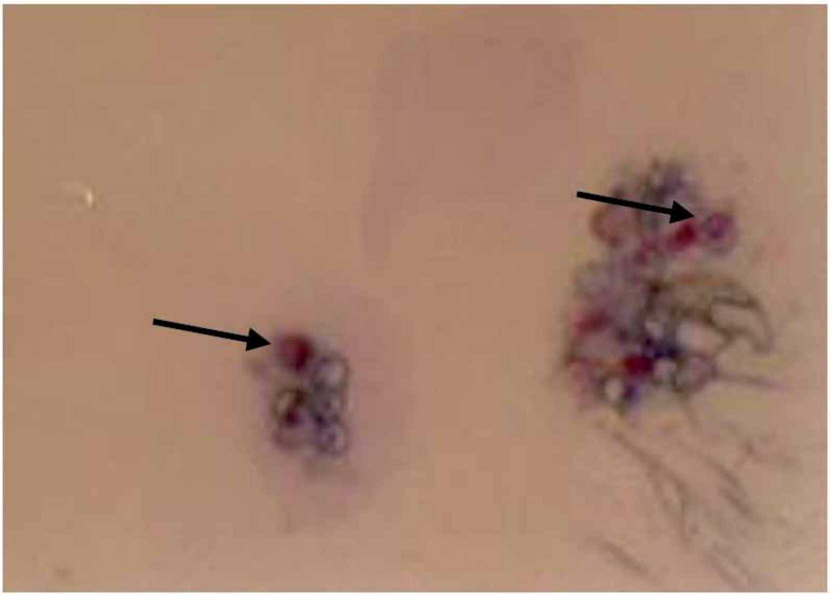

Figure 2.
Cryptosporidium spp. in fecal smear (Ziehl-Neelsen stain, oil immersion, 100X). Arrows show deep pink oocysts. (photograph by Alonso-Fresán).

Not only lambs may be infected through the fecal-oral route, but they can also get infected by drinking contaminated water. This may happen due to the high number of oocysts released to the environment and their resistance to chlorine and other conventional disinfectants used in water treatment processes. Oocyst concentrations of more than 150/L of surface water have been found in agricultural run-off water [15]. Therefore, another effective way of preventing Cryptosporidium spread into the environment and watersheds is using vegetation buffers, which aid in the retention of oocysts (**Figure 2**) [107].

Proper composting of manure (>60°C) inactivates oocysts and reduces the risk of their viability. Slurry storage produces ammonia and low pH, and anaerobic digestion using mesophilic and thermophilic bacteria also helps reducing oocyst viability. Fencing sheep away form water sources prevents water contamination with feces [108].

Even though many antigenic target candidates have been characterized, there is still no vaccine with proven effectiveness or ideal cost–benefit ratio [109].

8. Conclusion

Cryptosporidium spp. is a ubiquitous parasite that directly affects animal welfare by producing self-limiting diarrheas in immunocompetent hosts. In lambs, it is capable of producing a weakening diarrhea which may lead to death. The disease may be complicated by the interaction of other pathogens such as *E. coli* or *Salmonella spp.* Asymptomatic sheep may excrete oocysts, becoming a source of infection and contaminating the environment. Prevalence worldwide in sheep herds may be up to 100%. To prevent the disease, hygiene measures should be taken to avoid environmental contamination. Pregnant ewes should be separated from the herd during and after parturition. If lambs get infected, they should be treated in the same way as with any other diarrheic disease, with fluid therapy.

Many active principles have been tested, as well as alternative natural remedies such as plant extracts in an attempt to cure cryptosporidiosis which have only shown to reduce the number of oocysts excreted, mildening the disease in lambs and reducing environmental contamination, but none of them cures the disease. Vaccines are still in development as means of prevention. Even though there is neither a specific treatment for curing cryptosporidiosis nor a vaccine, manure should be properly composted and to avoid water contamination, vegetation buffers may be used.

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This book provides an overview of sheep husbandry in different parts of the world, including information on production and management systems, reproduction, and animal health. Chapters discuss different types of sheep and sheep husbandry in Poland, India, Africa, Spain, and North America, as well as zoonotic diseases such as cryptosporidiosis and their adverse impacts on the economics of sheep herding. This book is a useful resource for producers, veterinarians, animal scientists, researchers, biologists, students, and other interested readers.

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