Extensive Sheep and Goat Production

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Sheep and goat extensive production systems are conducted in many different parts of the world, and they often use essentially marginal areas unsuitable for crop production, characterized by low productivity per animal and per surface area. They positively impact local socio-economic activities, playing an essential role in the maintenance of rural communities, on ecosystems, and in the production of unique, valued foods such as lamb meat or cheeses. However, such systems are under significant pressure, mainly because there is little labor availability, and they have traditionally low productivity and often poor economic viability.

extensive technology PLF sheep goat omics

1. Sheep and Goat Extensive Production Systems: The Importance of Assessing Welfare

Extensive farming is generally perceived by society and consumers as a more sustainable and animal-friendly method of animal production. However, this remains to be validated by science. First, the welfare of animals kept, permanently or temporarily, in these systems must be scientifically and transparently studied [1][2]. Multiple approaches have been used to assess sheep and goat welfare in intensive systems [3], but ways for adapting and integrating this knowledge into protocols for small ruminants in extensive systems is still open to discussion.

The first welfare assessment protocols using animal-based indicators were developed for intensive production systems, especially for dairy/beef cattle, poultry, and pigs (for example, Welfare Quality), due to the overall high animal density per unit area associated with such systems. On the other hand, welfare assessment protocols for small ruminants, developed under the Animal Welfare Indicators (AWIN) project [4][5], were tested in different rearing conditions: dairy goats kept in intensive systems and sheep in extensive and semi-intensive farms [4]. Although these protocols may be useful for the assessment of welfare in all systems, it is necessary to ensure that appropriate and evidence-based changes are inserted and integrated. For example, some original measures may not be applicable or may show a very low prevalence and should thus be withdrawn, while new indicators will undoubtedly need to be added. Additionally, the assessors may need to record variable indicators dependable on various factors (for example, terrain, distance, access, time, and weather constraints). Recently, it [6] tested the feasibility and reliability of the AWIN protocol for the welfare assessment of dairy goats in semi-extensive farming conditions. It showed that some indicators from the AWIN sheep protocol could be successfully integrated into the original goat protocol, but some validation ones were nonetheless still needed.

It was discuss some of the main limits of these protocols when applied to fully extensive systems, as an opportunity for the use of novel technologies that are presented in the following sections.

Neither small-ruminant AWIN protocol includes males in the evaluation. Although this is not an issue for dairy cattle or pigs in intensive farms, it may be an important flaw for extensive and pasture farming systems [7][8][9]. Most published ones only assess the welfare and behavior of males in relation to the use of reproductive technologies [10] or in castration [11]. When applying an assessment protocol, it should be remembered that behavior is inherently different between females and males and that the presence of males may influence the behavior of the females (and vice-versa); for example, ewes are usually more active and vocal than rams [12][13]. Consequently, the welfare of males in the flock has often been overlooked. Therefore, developing or adapting protocols to groups that include males should consider such particularities.

Some proposals have been made to adapt existing protocols to less intensive farming systems [6][14][15][16][17] although this should be regarded as a complex and challenging task considering the settings' diversity [3][16]. Small ruminants bred in extensive farming systems are more exposed to weather conditions, which implies a need for considering temperature, humidity, and even wind exposure in welfare assessments. Extreme conditions, as well as sudden variations in weather, may significantly change the expression or intensity of some indicators and, thus, the welfare of the animals. Heat stress must be considered in these evaluations as well as each breed's capacity to adapt and cope with its environment [18]. Breeds selected to live in extensive or pasture farming systems are usually more resilient and well adapted to the climatic conditions [19][20]. However, when exposed to temperatures outside their thermal comfort zone, more sturdy animals may mask poor welfare signs, making assessment very difficult [20]. The volatility of these circumstances poses an enormous and complex challenge for welfare assessment in small ruminant species kept in harsher environmental conditions. Nevertheless, indicators related to thermal comfort should be seen as an essential component of protocols to be used in extensive farming systems. For example, weather and environment monitoring stations may be important assets as they will allow for accurate correlations between welfare indicators and weather conditions. Other ways novel technologies may help in overcoming some of these issues will be further addressed in subsequent sections.

One of the principles suggested by the Animal Welfare Indicators (AWIN) protocol is good housing. Although in extensive systems actual housing is very limited or even absent, the provision of shade or shelter from wind, rain, or snow should be considered as the lack may result in very poor welfare, particularly for young animals. Providing some sort of shelter, whether for feeding or for protection from climate extremes, will result in higher welfare levels [21][22]. However, the extension and type of landscape in which these animals are generally kept may preclude the building of such shelters [3]. Thus, including the presence of shade/shelter and its accessibility, should be considered as an important indicator of animal comfort.

Extensively kept small ruminants may be more prone to lameness problems due to constant exposure to wet soils and infection agents or due to the need to walk long distances along rough paths. Additionally, they are usually less frequently checked for signs of pain or discomfort and very rarely treated early, compared to animals in intensive farms [14]. Although conducting a thorough hoof examination poses great challenges in extensive systems, lameness assessments should include traditional gait scoring but also the careful examination of hooves if the prevalence of severely lame animals is detected. Moreover, the time of the year, climate, and terrain conditions should also be considered in these protocols. Technologies such as thermography, image scanning, or weight pads may be an expeditious and reliable way of detecting lame animals going through a race.

Several other problems deserve special attention in extensively kept flocks due to potential differences in prevalence and severity when compared with intensive systems [23]. Body condition score, diarrhea, and fleece condition are just a few examples of measures that may need substantiation and critical analysis before being approved [16][24]. These may vary according to weather conditions, season, and type of feeding (e.g., fresh grass), and the welfare impact of these changes must be verified. In extensive systems, in which the handling of individuals may be difficult, sorting gates and electronic weighing scales combined with e-ID may be used for the automatic collection of weight data.

Well-designed ones on the behavior of small ruminants in extensive conditions are required to ensure the validity of the many animal-based measures, including the group mental state assessment trough the Quality Behavior Assessment (QBA) used in the existing AWIN protocols [25]. Despite the merit of on-farm welfare assessment schemes like the AWIN protocols, there is a need to introduce indicators that address positive aspects of animal welfare [26]. In this sense, other methods, including the five-domain model, were developed [27] and applied to sheep [14][28]. This model incorporates three survival-related domains (nutrition, environment, and health), a behavior-related domain, and a fifth domain that results from a comprehensive assessment of how the other domains impact the animal’s affective experience [29][30]. Besides, it is an ever-evolving model [31], which also allows for new interpretations and adaptations to extensively farmed species. In this way, identifying valid, reliable, and viable animal-based indicators related to the positive aspects of animal welfare will improve the quality of life of animals and strengthen communication about animal welfare to stakeholders [31]. Likewise, measuring human–animal interactions in extensive systems might differ from the intensive systems norm. Therefore, it is relevant to combine the knowledge acquired in intensive systems, but also to understand how the human–animal interaction is in extensive systems, and to not infer by mistake that the applicable behavioral parameters might be the same.

An equally important issue in applying protocols to extensive systems is feasibility. For example, the time needed to apply the protocol in very large settings, or the difficulties associated with the exposure to open-field constraints, all have to be considered to ensure validity and feasibility. In this context, on-farm welfare assessment feasibility can be increased by adopting a strategy supported on a few valid and reliable animal-based indicators [14] complemented by the introduction of new technologies, such as automatic-recording devices or drones [32].

Finally, a word on an often-demoted issue—the need for specifically trained evaluators [6][33] so that the repeatability and credibility of the protocols are guaranteed. Experienced and competent auditors in intensive system assessments may not be prepared needed in extensive settings.

In summary, welfare assessment of extensively kept small ruminants should be seen as a very specific subject, and not just an extension or simple adaptation of the protocols validated for intensive systems. Due to particular features and limitations, full-field assessment may be too difficult to manage through traditional farm-level personal observation. This provides excellent opportunities for new sensor technologies, as will be discussed in the following sections. The main constraints to the use of new technologies in small ruminants in extensive settings, such as drones, intra-ruminal sensors or ear-tags containing accelerometers, are cost and the difficulty of getting accurate, real-time readings.

2. The Use of Precision Livestock Farming Applied to Sheep and Goat Extensive Production

Technological developments that have been applied to sheep and goat extensive production systems, although very diverse, can be framed within the concept of precision livestock farming (PLF). PLF has been described as the use of real-time monitoring technologies to manage the smallest manageable production unit [34]. PLF uses equipment, data, and software that allow individual animal information to guide decisions and inputs more precisely in an animal production system [35][36]. As mentioned, PLF approaches critically depend on identifying the animals individually, and electronic identification (EID) allows the achievement of this goal. EID has undergone significant developments since the early 1980s and is typically linked to the use of tags or boluses [35]. In 2004, the European Union made EID mandatory for all sheep and goats [37], and it currently represents an opportunity to further increase the scope of PLF technologies into extensive management systems [36]. EID is linked to technologies such as global positioning systems; behavior–activity loggers; virtual fencing; stationary management systems, such as walk-over-weighing systems; and automatic drafters [35][36][38]. These technologies allow for the precise management of sheep and goats, individually, in small groups, and as a flock [34][38]. Individual animal performance provides support for better decision making, which could benefit animal performance, economic performance, labor [37], and animal health and welfare [39]. As these management systems develop, vast amounts of data can be collected from thousands of farms, further assisting and directing agricultural policies on sheep and goat production, global warming mitigation, and antibiotic resistance [36]. Furthermore, such precision data can be used and integrated to find solutions to disease, welfare, productivity, and environmental issues and improve farming outputs [39][40][41]. Also, positive economic results have been observed in different reports [37][42]. As extensive systems are very diverse, there are many circumstances in which PLF is not suitable or even feasible. Despite promising results, most of the technologies have not yet reached an applicability level similar to those introduced in intensive systems [35]. It should also be considered that cultural dynamics, financial stability aspects, confidence in new technologies, and the openness of farmers to new ideas do not always encourage wider adoption of innovative technologies in sheep and goat extensive systems [36][43]. In this sense, and considering that PLF is a collection of relatively novel technologies, the effects on animal welfare in extensive systems are not yet apparent [40]. However, it is expected that PLF solutions will play a key role in assessing welfare in extensive systems and will be driven by a greater capacity of technologies to recognize welfare and, more significantly, whether the welfare of farm animals is improved by the application of technologies [40]. Nevertheless, available solutions that include PLF approaches have been used to assess various issues related to sheep and goats' health, behavior, and welfare in extensive systems.

3. The Use of Omics Applied to Sheep and Goat Extensive Production

Omics refers to the use of novel molecular biological approaches that allow for the profiling of a particular organism, tissue, or cell concerning its genes (genomics), mRNA transcripts (transcriptomics), proteins (proteomics), and metabolites (metabolomics) at a particular point in time [44]. Post-genomic platforms, namely proteomics, metabolomics, and transcriptomics, are gaining importance in the context of animal production, and more recently, the integration of these different platforms with food and nutrition science have been demonstrated to be a very interesting asset to obtain an in-depth analysis on animal physiology, production, and other related fields of animal science [45]. Despite many are concerning animal welfare in the behavior and ethology fields, the establishment of biomarkers can be a great complement to improving the welfare assessment [46] and the knowledge of animals' physiological processes and regulatory mechanisms of adaptation to harsh conditions [47]. Overall, it can be considered that the different omics are a valuable tool for addressing several key aspects of small-ruminant science, particularly in the framework of production and welfare in extensive sheep and goat farming. However, there is an aspect that is particularly associated with small-ruminant-production systems. It is related to the year-round fluctuations in the rain pattern that in turn cause important changes in the availability and quality of pasture and fodder for ruminants, particularly those in the extensive systems. Indeed, the occurrence of a dry season that can last several months leads to the unavailability and lignification (decreased nutritional value) of pasture during such months. In turn, this leads to seasonal weight loss (SWL), a problem to which several small ruminant breeds have adapted over the selection process. This issue is particularly pertinent in the framework. SWL is one of the most pressing issues in extensive animal production in tropical and Mediterranean regions. There are two solutions to address this problem. First, supplementation with additional feed is often problematic, if not impossible, to implement in the large areas that characterize these extensive systems. Second, the most cost-effective approach is using breeds adapted to feed scarcity [48]. To select such breeds, novel technologies are available, allowing for the identification of biomarkers and molecular patterns related to SWL resilience. Using omics have been conducted over recent years [49]. Here, it will be focus on two examples where omics were used to know SWL: meat-producing sheep in Australia and dairy-goat production in the Canary Islands.

Sheep production in Australia is mainly based on extensive systems, primarily designed for wool production using the Australian Merino (AM) breed. In recent years, these production systems have been increasingly exposed to droughts that compromise animal welfare and the economic viability of farms due to undernutrition [50]. Moreover, AM sheep are highly susceptible to myiasis (caused by blowfly strikes), which compromises their health and welfare [51]. To deal with this issue, farmers routinely remove the hind-quarters skin folds which are susceptible to blowfly strikes in a surgical procedure called mulesing [52]. In addition to decreasing wool prices and the consequently reduced profitability of AM flocks, these welfare concerns have motivated a shift in these production systems. Indeed, producers have been steering towards meat production, particularly destined for live animal exports bound for the Middle East and Asia. Because the AM sheep is primarily bred for wool production and is also highly susceptible to SWL and external parasites, it is less appealing for meat production compared to South-African breeds such as the Dorper. The latter is a composite breed conceptualized for meat production, originating in the breeding of Persian Blackhead and Dorset Horn. In addition to this breed, using fat-tailed breeds (for example, Damara, another South-African breed) poses another alternative, taking advantage of their superior fat depots to endure SWL [53]. To evaluate the response of the AM, Dorper, and Damara to SWL, a live-animal trial was carried out to induce weight loss experimentally [54]. Since then, several different analytical approaches have been carried out to assess the physiological response of these breeds. Briefly, the restricted groups of Damara and Dorper lost a smaller percentage of their initial live weight (LW) than the AM group. Unrestricted animals increased by 7%, 13%, and 10% of their initial LW, respectively [54]. The differences between breeds extended to carcass and meat characteristics, with both South-African breeds having heavier carcasses, higher fat deposition, and darker meat compared to the AM breed [55]. The different muscle development inherent to each breed was reflected in the muscle proteome [56][57]. The muscle structure of the Dorper breed is particularly affected when restricted, lowering the abundance of contractile apparatus proteins, such as myosin and tubulin. In addition, a higher number of cellular functions were impacted in the AM breed as a consequence of SWL, such as ATP and actin binding [56]. This was corroborated by a metabolomics [58] and amino acid [59] profiling analysis of the muscle tissue, which identified lower levels of amino acids (for example, tyrosine, glycine, and taurine) in the muscle of the AM breed, suggesting lower muscle growth and increased endogenous protein mobilization compared to the other two breeds. Interestingly, the Damara breed was seen to increase the abundance of structural proteins such as desmin because of SWL [57]. This highlights an increased resilience of Damara sheep under SWL, where they counter-balance muscle amino acid mobilization [59] by attempting to maintain structural integrity. The liver proteome of these sheep has been learned, including the mitochondrial proteome [60][61]. These revealed that the Damara breed under SWL mobilizes more lipids than the AM breed through the higher abundance of lipid transport proteins, such as apolipoprotein E, and lipid metabolism proteins, such as annexin. In turn, the unrestricted group has a metabolism oriented for the synthesis of fatty acids, particularly branch-chain fatty acids, which accumulate in the tail [62]. Indeed, the mobilization of tail fat under SWL is the distinct mechanism of the resilience of the Damara breed against SWL. Its mobilization has caused the increase of fat tissue mineral concentrations [63] since the presence of fat has a diluting effect on the tissue mineral profiles [64]. The quality of wool from the AM breed was also negatively influenced by SWL, which caused a reduction in fiber diameter and an increase of the high-sulfur protein KAP13-1 and the glycine–tyrosine-rich KAP6 family of proteins [65]. The data mentioned above demonstrate the physiological mechanisms behind the improved adaptation of SWL of the Dorper and Damara breeds compared to the AM breed. Moreover, several different biomarkers have emerged from these ones that can be used to choose hardy breeds whose welfare is not so negatively affected by current conditions.

Dairy-goat production in the Canary Islands is another example where the reared animals are subjected to SWL, particularly in the easternmost islands, which are very dry compared to the western islands with a more temperate climate. The different rainfall in La Palma (a humid island) and Fuerteventura (a dry island) has an impact on the available pasture, and consequently, on animal production. The Majorera goat from the latter island has been adapted to weight loss, whereas the Palmera goat from the former is more susceptible to feed restriction, which threatens welfare in dairy production systems. Similar to the sheep example described above, a trial was conducted to compare the response of both of these breeds to SWL. Restricted groups lost 13% of their initial live weight and 87% of their initial milk yield [66]. This had repercussions on the FA composition of milk and the mammary gland, particularly for the Palmera breed, where restriction increased oleic acid and reduced palmitic acid in the secretory tissue, whereas the Majorera had no differences [67]. Despite this, feed restriction caused the mobilization of endogenous FA in both breeds, as indicated by higher levels of circulating non-esterified FA [68]. However, omics approaches have revealed that the response was different in the two breeds, with more resistance features in the Majorera. Indeed, a transcriptomics approach identified a wide set of genes with differential expression in the mammary gland caused by SWL. The restricted Majorera increased the expression of genes related to amino acid, lipid, carbohydrate, and nucleoside transport, indicating reduced metabolic activity. Contrarily, the restricted Palmera goats upregulated genes involved in suppressing cell differentiation and related to the response to DNA damage, demonstrating the effects of mammary gland involution. Comparing both restricted groups identified two genes associated with unregulated tissue development in Palmera goats (CPM and ASB11) [69]. This is confirmed through two different proteomic approaches that identified a high abundance of apoptotic proteins in the restricted Palmeras and suggested cadherin-13, collagen alpha-1, and clusterin as another set of putative biomarkers to SWL tolerance in the Majorera goat breed [70][71]. The detrimental effect of feed restriction extended to the metabolome of the mammary gland and milk [72]. Restricted groups had lower AMP, ADP, ATP, and IMP, all energy-related molecules characteristic of low metabolic rates in both restricted breeds. In addition, feed restriction influenced the rumen metabolism, which seems to have contributed to the lower levels of Krebs-cycle intermediates (citrate, fumarate, succinate) in the milk of the restricted goats. So, as SWL can represent a problem in the dairy sector, it is essential to establish biomarkers to ensure the health-status monitoring, apply new breeding systems, and essentially guarantee animal welfare [47][73]. Similar to the Australian sheep, these goat have yielded several putative biomarkers of SWL-resistance that could be used to select animals for enhanced response to SWL. This is particularly important given that the climate is rapidly changing, and susceptible breeds could soon be subjected to harsh droughts that threaten not only animal welfare related to undernutrition, but also local food security and economies.

The information obtained from these omics approaches provides a detailed look at the impact of SWL on a molecular level. This allows for a deeper understanding of the metabolic response to weight loss differentiation among adapted and susceptible breeds in two distinguished contexts: dairy and meat production. The identified differences are supported by classical approaches, including mineral, amino acid, and fatty acid profiling. Identifying biomarkers for SWL-resistance enables the improvement of breeding programs for the selection of hardy breeds towards the economic viability and welfare of animals in the extensive production systems in tropical and Mediterranean regions.

4. Novel Technologies and Thermal Stress in Sheep and Goat Extensive Production

Climate change poses severe threats to livestock production, particularly in extensive small-ruminant production systems. A negative impact on livestock production and productivity are expected with the temperature increase and the frequency of extreme weather. Consequences will likely be even more severe in arid and semi-arid grazing systems where higher temperatures and lower rainfall are expected [74].

In this changing climate scenario, environmental challenges stimulate behavioral responses in animals. The welfare status is directly linked to livestock behavior, and hence change in the behavioral pattern will help determine urgent environmental conditions. As the behavioral response is the first step animals take to cope with the heat load, animal behavior is valuable to understanding how to best use and design strategies to cope with the environment. However, the impact of heat stress and the animals' responses are difficult to predict and analyze; thus, a better understanding of the response of the animals under heat stress is required. Several technologies and methodologies have thus been proposed to monitor small-ruminant temperatures under field conditions, as subsequently detailed.

Automated monitoring of behavior using digital technologies might increase labor efficiency. It has been suggested that such technologies would allow farmers to better monitor and manage animals, resulting in a higher efficiency in production, lower environmental impact, and improved animal welfare [75]. Technological advancement has made this task more accessible with the help of recording devices. Other tracking devices. Such as access-control systems, lasers, video systems, and video systems combined with GPS and cell phones have also been attempted in livestock research [76][77]. GPS tracking devices offer the potential to monitor behavioral measures, such as shelter-seeking, remotely and to determine how shelter availability influences paddock utilization by ewes [78]. These products can benefit the farmers as they can provide some rudimentary surveillance of the sheep. For example, during hot summer weather, night grazing increases as animals seek shade during hot hours of the day. Another recent technology development has been integrating radio frequency identification (RFID) sensors capable of monitoring animal behavior [79]. RFID sensors can provide permanent individual identification of animals, and readers can identify several animals simultaneously. In addition, the RFID technology allows the frequency and duration of animal visits to the feed bunk and water troughs to be recorded, and this can be used to assess feeding and water intake behavior. While these products can be of significant help, they have some limitations. Indeed, the sampling frequency is relatively low, and wooded areas also make it challenging to locate the exact position of the animals [80]. Even so, the information provided only by the GPS is insufficient; knowing where the animals are in the pasture does not provide information about their behavior or activities. However, the simple behavioral classification used in conjunction with GPS tracking in sheep has led to the distinguishability between "active" and "inactive" behavior [81]. GPS used in combination with accelerometers allows for the identification of more complex behaviors, such as rumination, movement, grazing, standing, walking, lying down, and running [82][83]. Recently, it was mentioned that raw accelerometry can be used to predict discrete numerical signatures associated with sheep's grazing, resting, and walking activities. This type of sensor can be a very effective tool for identifying sheep grazing activity [84].

The rectal temperature has long been used to evaluate core temperature and quantify the heat stress response in livestock. An extensive one on automatic data collection in heat-stressed sheep refers that manual clinical thermometry is not appropriate for assessing circadian patterns of body temperature in free-range animals or those in extensive grazing systems [85]. The vagina is another good site to collect temperature. Vaginal temperature (VT) sensors correlate with rectal temperature measurements [86]. Notwithstanding, attention must be paid to the changes in vaginal blood flows during the estrous cycle and gestation stages because the vaginal temperature can change accordingly [87]. Devices such as rectal probes have the advantage over traditional thermometry as they enable producers to measure temperature remotely. Rectal probes record core temperature most consistently, particularly in male animals, despite a relative degree of invasiveness. Therefore, it is likely that the stability of rectal probes could limit the accuracy of temperature data in sheep [88][89]. A range of subcutaneous microchips and other implantable devices is also being developed to measure body temperature in livestock continuously. Typically, microchip transponders are injected under the skin and activated through a handheld receiver, where the temperature reading is then relayed instantaneously [85]. The intra-peritoneal, or intra-abdominal, area is the most common site for implants. The temperature loggers surgically implanted into the peritoneum display with accuracy the subtle body temperature changes in sheep exposed to hot conditions [85].

Intra-ruminal temperature sensors have arisen as a non-invasive alternative to the surgical implantation of devices. Temperature loggers consisted of a chip, antenna, and battery built into an orally administered bolus. This technology enables real-time data collection through instant wireless transmission [90] or stores the information until the animal is in the vicinity of a receiving antenna [91]. Rumen temperature is highly correlated with core temperature, even though the ruminal temperature is higher than the core temperature by approximately 2 °C. This difference can be reduced (by almost 1 °C) during fasting and drinking episodes [92][93].

It is scarce despite the potential impact of rumen temperature sensors to investigate heat stress in sheep or goats [94]. Infrared thermography, which measures real-time surface temperature distribution, is a tool that is being increasingly used in farm animals due to society's growing interest in animal welfare. From a physiological perspective, the differences in the thermal image reflect changes in blood flow that allow thermal exchange between an animal's skin and the environment through vasoconstriction or vasodilatation [95]. However, it was conducted in this field often lead to question the usefulness and viability of the thermal windows currently suggested for ruminants since certain anatomical aspects, such as hair, skin color or the lack of it, and skin thickness, can affect specific thermal windows, making them unviable in these species [96][97].

Concerning well-insulated wool sheep, it is known that environmental heat exchange is profoundly affected by fleece length. One effect of shearing is that it causes the skin to thicken, which influences heat transfer at the skin's surface [98]. In a high-temperature environment, it is essential to understand better the adaptive capabilities of animals and use the appropriate tools to quantify their responses to heat stress. On the other hand, to improve welfare, it is necessary to mitigate the effects of high radiant temperatures and high solar radiation that can trigger severe heat stress. In extensive grazing systems, controlling the ambient temperature is impractical. Providing some shade for the animals and sufficient water is usually all that can be achieved. Shade trees reduce heat stress on animals and help increase productivity [99]. It has been shown that the beneficial effects of providing shade or shelter to sheep to decrease the heat gain by solar radiation. It was found that shaded sheep are more productive and have less severe physiological responses than unshaded sheep [100]. The magnitude of these effects depends upon the height, the canopy type, and the trees' density [101]. In general, silvopastoral systems are considered beneficial for animal welfare, despite the variability of tree arrangements [102]. Silvopastoral systems are attractive alternatives for reducing heat loads and increasing animal thermal comfort. Sheep reared in silvopastoral systems tend to increase their time in grazing and reduce by 10% their water consumption [103]. The projected shade of trees with denser foliage offers better protection against solar radiation. However, beyond the dimension and position aspects of shade, it is crucial to consider the adequate protection given by any shade.

In the Mediterranean, the protection against solar radiation of pine trees (Pinus genus), olive tree (Olea europea) and cork and helm oaks (Quercus ilex and Quercus suber) is very distinct, with better shade quality usually associated with cork oak trees. Silanikove [100] found that, in the summer Mediterranean region, unshaded sheep had a respiration rate that was 56% higher than that of sheltered sheep due to the effect of direct solar radiation. However, Johnson [104] found that unshaded and shaded animals all maintained similar body temperatures and respiratory rates, despite the possible advantages of shading. It was thus suggested that wool length greater than 20 mm might have substantially slowed radiative gain. Providing shade, either natural or artificial, in regions or production systems prone to heat stress problems seems thus to be a practice to be implemented and encouraged.

Improving the welfare of domesticated ruminants subjected to climatic change is a new challenge. Therefore, future selection in small ruminants should aim to balance heat adaptation, health, and production. The main objective of future selection to sustain small-ruminant production should focus on several specific adaptive characteristics [105], preferably combining heat tolerance with SWL tolerance as detailed in the previous section. Essential traits to consider in such selection could be skin and hair type, sweat gland capacity, reproductive rate, feed conversion efficiency and drought tolerance, and metabolic heat production. In addition, the adapted local breeds could be a gene bank alternative as an appropriate bio-resource to sustain small-ruminant production under changing climatic conditions.

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