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# Sustainable sheep production and consumer preference trends: Compatibilities, contradictions, and unresolved dilemmas

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ABSTRACT

There are increasing concerns of society towards the consumption of animal products which have been produced and transformed in a sustainable manner. This trend influences consumer purchasing decision making, particularly in developed countries. On the other hand, in the next years, the pressure to increase the volume and efficiency of meat production will be much higher to cope with the expected unsatisfied demand. At least in part, current and future technologies could contribute to solve this challenge. However, the use of some of these innovations could have a negative effect on consumer preferences. There is no consensus in our society about this dilemma. The objective of this paper is to review the scientific evidence related to these topics and to analyze and discuss the effect of some of the extrinsic and intrinsic factors linked with the sheep industry which could affect the acceptability of lamb meat by consumers.



## 1. Introduction

By the year 2050, the agriculture sector has the challenge to increase production over 60% to feed the world (Food and Agriculture Organization of the United Nations (FAO), 2012). In this scenario, meat consumption, as a strategic source of protein in human diet, is expected to grow substantially. The projected demand shows that the leading position will be taken by poultry and pig meats, followed by bovine and sheep meats, respectively. World meat exports will grow by 19% in 2021, primarily driven by poultry and beef, where supply and demand will come mainly from North/South America and Asia/Latin America/oil exporting countries, respectively. In particular, expected growth in sheep meat for production and consumption (22% in volume; 4% in price in real terms) between 2009–11 and 2021, will be driven mostly by developing countries.

After the reduction in global supplies of sheep worldwide during the last decades, Rowe (2010) highlighted that sheep meat market share will be recovered, associated with price incentives in comparison with other meats. The traditional importing markets (e.g. EU and USA) will be expanded by increasing demand from developing countries with growth in income such as China, Saudi Arabia, Jordan, United Arab Emirates, India, Turkey and Qatar (Food and Agriculture Organization of the United Nations (FAO), 2012).

Food and Agriculture Organization of the United Nations (FAO) (2012) mentioned that in some countries, this expand in demand could promote increases in productivity through the use of better genetics and finish lambs on grain. New Zealand and Australia are two potential candidates to take advantage of this market opportunity. However, in both countries, production orientation is dominated by pastoral production systems (Bray & Gonzalez-Macuer, 2010; Cottle, 2010), and the use of feedlotting is restricted to Australia (only 14% of total lamb slaughtered comes from feedlots) to supply mainly the niche of the USA's lamb market. Rowe (2010) posed that sheep meat cannot compete with poultry or pig meat in volume or price, therefore, the alternative way is to focus more on differentiation based on quality and consistency.

In the next 50 years, there is no doubt that research and innovation will play a key role in increasing food productivity in more than 100%. So, essentially, it looks that the sheep industry will have to face two main challenges at the same time: a) to increase production and efficiency, contemplating product differentiation, adding-value and consistency and b) to increase the speed of the technology achievements and adoption in order to compete successfully in the market with the other alternative meats. This is not an easy competition given the size and type of business and capital investment of poultry, pig meat and beef industries. Moreover, this will have to be done without decreasing the sensory quality of sheep meat.

From the consumer side, there is an increasing concern about the sustainability of the intensification of animal industries and its potential damages on the environment, human health, and animal welfare. In

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some segments of consumers, extrinsic factors (e.g. product origin, general production practices, animal welfare, social and religious values, climate change, water and air pollution, and human health) appear to be important clues in consumer purchasing decisions (Font i Furnols et al., 2006, 2009; Garnier, Klont, & Platow, 2003; Grunert, 2006; Saunders, Guenther, & Driver, 2010; Tilman, Cassman, Matson, Naylor, & Polasky, 2002; Troy & Kerry, 2010).

The need for more global sustainable agricultural was strongly addressed in the pass, but it has to be applied specifically to local values and constraints (Tilman et al., 2002).

The debate is open about the sustainability of the intensification of animal production systems and consumer perceptions related to this issue. In this article, the potential compatibilities, contradictions and unresolved problems associated with this dilemma will be addressed and discussed, and in particular applied to sheep meat.

## 2. Sheep meat production systems: intensification, research technologies, innovations, and trends

### 2.1. Automatization

Since 1990, in most of the leading sheep production and exporting countries like New Zealand, Australia and Uruguay, it is possible to see several structural changes in the sheep industries, such us: a) reductions of total sheep numbers, b) reduction or conversion of sheep farms, particularly the smaller ones, c) more specialization in wool and/or meat production, d) intensification and increases in productivity, e) sheep production systems concentrated on more marginal soils, f) aging of farmers, and g) less labor force available (and less qualified) to work in sheep farming (Montossi et al., 2011; Morris, Cronin, & Bush, 2012).

Under these social, economical and environment limitations, sheep farming has to be adapted to be more efficient with less resources, particularly those associated with environmental and labor force constraints. The use of new precise and accurate technologies that can increase productivity and efficiency with less labor unit/sheep heads and less time consuming are called to play an important place in future sheep farming. The move to automatization and use of more precise technology tools in sheep farming is an interesting and positive response in this direction.

The implementation of the concept of precision livestock farming is a relatively new concept applied to beef and sheep production systems. Precision livestock farming has been defined and applied for different situations and conditions (Berckmans, 2004; Laca, 2009a,b; Pomar, López, & Pomar, 2011; Rowe, 2006). In this sense, targeting several areas of science and livestock production and industries situations, some definitions are quoted in the literature as follows: a) "precision livestock farming is an innovative production system approach which is based on intensive and integrated use of advances in animal sciences and in the new technology of information and communication" (Pomar et al., 2011), b) "Precision livestock production is the augmentation of precision agriculture concepts to include all the component of agroecosystems, particularly animals and plant–animal interactions" (Laca, 2009b), and c) "Precision Sheep Management (PSM) describes a system whereby animals are managed as individuals or small groups rather than as a (whole) flock" (Morris et al., 2012).

These approaches about livestock precision management have different degrees of application to commercial situation, where the proposal of PSM of the Australian Sheep Industry Cooperative Research Centres (CRC) is very well advanced and currently implicated in Australian sheep farming situations (Cooperative Research Centre—CRC, 2013a, 2013b).

Rowe and Atkins (2006) stated that approximately 20% of the total flock contributes little to sheep farmer productivity and profitability, therefore measuring, monitoring, and processing animal performance to select the most productive individual is a key issue to keep competitive the enterprise.

Morris et al. (2012) reviewed and analyzed the application of PSM for Australian conditions. This system management is based on the combinatory use of (i) radio frequency identification technology (e.g. in ear tags), (ii) remote and automatic measuring and monitoring equipments (e.g. "walk-over-weighing" scale powered by solar panels, Pedigree Matchmaker, remote drafting systems applied for selective supplementation technologies), and software specially designed for processing and analyzing the performance information recorded in general or specialized sheep enterprises (e.g. in stud breeders). A list of different devises, equipments, and software which are currently utilized by farmers are listed by Cooperative Research Centre—CRC (2013a, 2013b).

In addition, the Spanish farmer cooperative "Los Pastores" is using an integrated information system in its lamb classification and fattening centers. These centers gather, process, and analyze information to improve productivity and consistency of the products offered to the market. This process has been evaluated also in relation to the stress generated by the logistics implemented as well as the effects on meat quality (Miranda de la Lama et al., 2009).

The productive and/or economical benefits of the application of PSM (based on individual recording) were demonstrated to: a) save labor costs and use more efficiently farmers' working time (Cooperative Research Centre—CRC, 2013a); b) improve sheep genetic progress (Atkins, 2010), c) apply remote drafting technology for setting sheep individual performance through supplementation under grazing conditions (Bowen, Pepper, McPhie, & Winter, 2009), and d) improve individual performance which can drive positively the productivity and profitability of the whole enterprise (Haigh, 2010).

In addition, Haigh (2010) mentioned that these technologies can also reduce animal's stress by minimizing animal movements and confinement in yards; therefore they can improve animal welfare. This effect is particularly important in the context of the claims made by animal welfare organizations (e.g. People for the Ethical Treatment of Animals) about the ethical and moral obligation of farmers to provide close monitoring of animals and proper animal husbandry practices to ensure animal health and welfare.

Morris et al. (2012) concluded that PSM technologies contribute with enhancing productivity, profitability and reduce animal welfare concerns for Australian sheep industry associated with low monitoring and recording frequency performed by stockmen. The same authors also mentioned that the major limiting factors to increase the adoption of the PSM are: a) the initial investment needed (see cost ranges for different options at Cooperative Research Centre—CRC (2013b) for small scale producers and b) the age restrictions and informatics skills of farmers to be motivated and encouraged to use these novel and more sophisticated technologies.

### 2.2. Genetics

Sheep farmers around the world are generally characterized by their extensive systems, making use mainly of grasslands, often located in marginal areas, to produce meat, wool and milk. As world population rises, production of food and fibers from marginal lands will become increasingly important. Therefore, sheep industry is likely to have an opportunity to this increased demand (Macfarlane & Simm, 2007; Mueller, 2008). For example, in 2006, according to FAOSTAT (2007), there were around 1.1 billion sheep in the world producing approximately 13 million tons of sheep meat.

During the past half century, the less industrialized countries experienced rapid increases in animal production through both large-scale confinement systems and traditional small-scale systems. These countries now produce the majority of the world's meat (Fraser, 2008).

Increase productivity and efficiency of lamb meat production is a key factor to augment the competitiveness of the meat sheep industry. Reproduction rate, lamb growth and carcass quality have a major influence on producer returns. All of these traits of economical interest can be improved through different nutritional and husbandry practices.

The potential changes that could be obtained by management and nutrition are affected by environmental conditions, particularly under extensive conditions. By contrast, genetic improvement of the traits contributing to lamb meat production is permanent, cumulative, cost-effective and sustainable (Mueller, 2003).

Overall benefits of exploiting complementarities of different breeds and heterosis are dependent on the genetic merit of the pure breeds available. Selection within breeds is more complex than selection between breeds (Leymaster, Shackelford, Wheeler, & Koohmaraie, 2006). Even where there is good evidence for the superiority of one breed over another, on average, there is usually substantial variation in growth and carcass characteristics within breeds (Macfarlane & Simm, 2007). So, there is a clear opportunity for the genetic improvement of these traits.

In the last few decades, selection experiments were established for various carcass traits in a number of countries, but particularly in New Zealand, Australia and the UK. Most of the New Zealand selection lines were selected divergently for ultrasonic backfat depth, adjusted for live weight (Macfarlane & Simm, 2007). In most of these experiments, rates of genetic change in excess of 2% per annum were achieved in fat depth (Simm, 1992, 1994). Simm and Dingwall (1989), in a research using an experimental Suffolk flock, where animals were selected over a period of 9 years based on a selection index combining information of live weight (LW), ultrasonic fat depth (UFD) and ultrasonic muscle depth (UMD), clearly demonstrated the positive value of genetic improvement in meat sheep. The breeding goal of this index comprised carcass lean weight and carcass fat weight at a constant age. On this basis, two selected lines were compared (control and selected). The genetic gains between both lines were higher in LW (+10%), lower in UFD (−13%), higher UMD (+13%) and higher for the index score (+18%) in favor of the selected line (Simm, Lewis, Grundy, & Dingwall, 2002). Similar responses were observed by Lewis, Simm, Dingwall, and Murphy (1996). Benefits of using higher index sires have also been shown to persist over a range of slaughter weights and nutritional environments (Lewis et al., 2006).

Banks (2003) discussed the evolution of the Australian prime lamb industry during the period 1980–2003. The industry was negatively affected during the 80s and early 90s by the low wool prices received by farmers, and began a slow recovery in the late 90s. However, from 2000, the industry has experienced an exceptional growth, where several sheep meat industry development programs helped in this recovery (e.g. Trim Lamb Campaign, Fresh Australian Range Lamb, and Lamplan). After this period, the same author demonstrated that the genetic improvement in productivity and product quality increased at 4% per annum from the late 1990s, generating a very competitive product (heavy and lean lamb carcasses; 18–22 kg). This genetic success was associated with a positive combination of aggregated improvements along the sheep industry, included better farm management, genetics, marketing and a consumer-focused industry. Continued progresses of carcass qualities can be achieved by improvements in leanness and increased muscling (Banks & Ross, 2003), which in turn will result more efficient production systems and greater meat yields for processors and retailers. Gardner et al. (2006) stated that lamb industry can implement further improvements through the strategic and intensive use of these genetic tools.

In a breeding program, it is important to monitor the genetic progress obtained as a way of verifying if the breeding goals are achieved, or adjustments are necessary. One way to analyze the genetic gains obtained is by visualizing the average breeding values of the different traits evaluated by generation as well as by studying the direction and speed of the change in each trait (Ciappesoni, Gimeno, & Coronel, 2011). In general, it is considered that an annual genetic progress of about 2% would be the maximum to achieve within a closed population which is concentrated on the selection of only one single characteristic (Ciappesoni et al., 2011).

In Uruguay, the genetic program of Texel (terminal sire breed), is using quantitative and genomic selection. From this program, some preliminary estimations for carcass quality traits (hot carcass, French rack, shoulder and leg weights, intramuscular fat and indicator of carcass fatness) resulted in moderate to high heritability ($h^2$; ranged from 0.3 to 0.5) (Ciappesoni et al., 2012).

In the last decades, intensive research work has been focused in ways to incorporate molecular information (markers in the DNA) to speed up the progress of genetic improvement programs. However, very little of this information has been included in current programs of sheep genetic improvement worldwide. The turning point happened, no more than a year ago, in the evaluations of dairy cattle in the USA, where it began to include the information of a new type of markers, the SNP (Single Nucleotide Polymorphisms). In the case of sheep, a marker panel ("chip") that enables the evaluation of more than 54,000 SNP in each animal is commercially available. In recent years, intensive genetic research has been devoted to study the information that can provide these markers and the form of how to incorporate into the genetic improvement programs. In Uruguay, there are currently two projects including this information to molecular improvement programs. One of them focused on genetic resistance to gastrointestinal parasites in Corriedale and Merino breeds (Ciappesoni et al., 2011). There is ample evidence to show that genetic variation for disease resistance exists between breeds and within breeding animals. It is clear that genetics will become much more important in the future to explain differences between animals and the effect that resistant animals have on the epidemiology of parasites (Karlsson & Greef, 2012).

Beh and Maddox (1996) concluded that the availability of markers for the resistance to gastrointestinal nematodes in sheep will enable the use of marker-assisted selection to increase the accuracy of selection in practical breeding programs in the next 20 years. In parallel, recording protocols, electronic data capture and databases to provide the phenotypic data necessary to support the animal genomic technologies must be developed (Bishop & Morris, 2007).

### 2.3. Production systems and healthier lamb meat

Meat is an important food group in the diet for many consumers, especially in developed countries (Delgado, 2003) and its consumption pattern can be explained by different variables (Speedy, 2003). World lamb consumption is around 2 kg per capita per annum (FAOSTAT, www.fao.org) with large variations between geographical regions (e.g. 17 kg in Australasia vs. 0.7 kg in North America), between countries and even between regions within the same country. In developed countries, the consumption of red meat is related with non-communicable diseases (cancer and heart disease) (McNeill & Van Elswyk, 2012). For consumers from developing countries red meat is a strategic food resource to reduce malnutrition. In these countries, diseases related to essential nutrient deficiencies coexist now with other chronic diseases (Schönfeldt & Gibson, 2008). Numerous epidemiological studies associated red meat consumption with a negative health image due to the content of fat (quantity and composition). Some works showed a positive correlation between fat intake and the incidence of colon and prostate cancer (World Cancer Research Fund (WCRF)/American Institute for Cancer Research, 2010), however, others (Howe, Aronson, & Benito, 1997; Hunter, Spiegelman, & Adami, 1996) did not find any association.

Lamb and beef meats are also a rich source of protein, providing 20 g/100 g of consumed meat, and necessary micronutrients (iron, zinc, selenium and vitamins) to human life, which are not present in vegetables or they have a low bioavailability (Biesalski, 2005). This condition in addition with the low content of carbohydrate of lean red meat could also be beneficial to reduce and/or prevent overweight, cancer or diabetes. It was assumed that impaired bioavailability of micronutrients is a problem in the elderly segment of world population (Viteri & Gonzalez, 2002). Williams, Droulez, Levy, Stobaus, and Sinclair (2002) reported for Australian lamb cuts an average iron content of 2.2 mg/100 g and Campo et al. (2008) reported for Spanish lamb (*ternasco*) levels of iron from 0.9 to 2.0 mg/100 g. Thus, lamb is a good source of iron since

from a 135 g of lean lamb provided 25% of the recommended daily intake (Food Standards Australia and New Zealand, 2004). However, lowering the recommended intake of 71 g/day of red meat, could affect the iron status recommended. For this reason, Pethick, Banks, Hales, and Ross (2006) suggested that lamb industry could implement selection programs to increase iron content in meat. They also demonstrated that iron content was positively correlated with selenium but negatively with α-tocopherol contents. The contribution of zinc by lamb meat is 3.3 mg/100 g, providing adequate level of this micronutrient for optimum health. Regular consumption of red meat can also help to decrease the risk of inadequate vitamin $B_{12}$ intake, which is associated with cardiovascular disease and stroke. In this sense Campo et al. (2008) showed that *ternasco* lamb is a good source of vitamin B (mainly niacin and riboflavin).

In recent years, human health concerns have increased in relation to fat consumption in red meats, resulting in human health recommendations towards higher intakes of polyunsaturated fatty acids (PUFA), particularly those of n−3, and at the same time promoting the consumption reductions of n−6 fatty acids with optimums of PUFA/SFA (saturated fatty acids) and n−6/n−3 ratios higher than 0.4 and lower than 4, respectively (Department of Health, 1994). Some controversies are highlighted in the literature about the usefulness of the n−6/n−3 ratio with concern that both PUFA are essential for human health (Givens & Gibbs, 2008), mainly in infant development (Harbige, 2003). Stanley et al. (2007) suggested the use of absolute values of n−3 and n−6 instead of its ratio. Wood et al. (2003) mentioned that some meats naturally have PUFA/SFA ratio of around 0.1 and some meats also have n−6/n−3 ratios higher than 4, showing the need to improve these ratios to produce healthy meats. In general, 50% of the intramuscular fat of beef and lamb is composed by mono-unsaturated fatty acids (MUFA), mainly oleic acid (C18:1 c−9) and PUFA, predominantly linoleic acid (C18:2 n−6) and α-linolenic acid (C18:3 n−3) (McAfee et al., 2010). The PUFA/SFA ratio for lambs from different countries and production systems varied between 0.19 and 0.38, being long chain (LC) n−3 PUFA (C20:5, C22:5 and C22:6) contents between 0.21 and 0.60 mg/g (Díaz et al., 2005). There is a variation in fatty acid composition associated with breed, sex, age, diet and within cuts (Wood & Enser, 1997). Most of the research efforts were focused on the change of fatty acid composition of red meat, since that increasing dietary ratio of PUFA/SFA could reduce the level of cholesterol in plasma and the risk of cardiovascular diseases.

Animal feeding has a major importance in changing meat fatty acid composition, influencing human health and consumer perceptions about feeding patterns (Álvarez, de la Fuente, Díaz, & Cañeque, 2007; Enser et al., 1998; Font i Furnols et al., 2009; McAfee et al., 2010; Montossi & Sañudo, 2007a, 2007b; Sañudo et al., 2000). In general, the intake of fresh or conserved forage in ruminants generates a lower fat deposition in comparison with those grain-fed. This is principally related to the lower energy concentration found in forages in comparison with concentrates, as well as the higher maintenance costs of grazing animals compared with animals confined in feedlots. The fatty acid profile in meat from grazing animals is rich in PUFA, mainly linolenic acid and its long chain derivates, while the profile in meat from animals fed with concentrates is rich in linoleic acid and its derivate arachidonic acid. Blas and Morand-Fehr (2000) reviewed dietary manipulation strategies to promote better fatty acid profiles in lamb fat deposits, showing that pastured based-diet increased C18:0 and C18:3 fatty acids in lamb tissues. Higher concentrations of LC n−3 PUFAs in meat from grass fed-animals compared with those of concentrate fed-ones (Enser et al., 1998) can also be detected in plasma and platelet of healthy consumers that consumed this meat (McAffee et al., 2011). Angood et al. (2008), comparing the fatty acid profile of lamb meat produced organically or conventionally in UK and sold in UK supermarkets, found higher levels of linolenic acid (C18:3) and total n−3 PUFA and lower linoleic acid (C18:2) in organic lamb meat compared with conventional although both production systems had a favorable n−6:n−3 ratio. Although these LC n−3 amounts in meat are lower than in fish and seafood, they contribute almost equally in countries like Australia where meat consumption is higher than fish (Howe, Meyer, Record, & Baghurst, 2006). In any case, for humans, meat composition and its contribution to the diet must be considered within the concept of a balanced diet.

Conjugated linoleic acid (CLA) was studied in ruminant meats for anti-carcinogenic properties in lab studies; however the biological effects in humans are still unknown. Díaz et al. (2005) in their study reported CLA concentrations between 0.40 and 1.05% in lamb from different origins and production systems. It has to be taken into account that fatty acid composition can be modified by post slaughter procedures, specially cooking system (Campo, Resconi, Muela, Oliván, & y Sañudo, 2009).

The interest for using more concentrates in lamb diets has increased for several reasons in many parts of the world.

In northern Europe, shorter production seasons, encouraged year round indoor finishing of market lambs. The use of more concentrate in the diet increases lamb performance and feed efficiency (Jacques, Berthiaume, & Cinq-Mars, 2011). In this sense, attempts to manipulate lamb fatty acid composition with different local resources of protein (e.g. legumes and oilseed cakes) had lower potential beneficial impacts on human health (Turner et al., 2012). Nevertheless fish oil/meals in lamb diets has an important effect on its fatty acid composition increasing n−3 fatty acids (see review of Raes, De Smet, & Demeyer, 2004), although too-high levels of fish oil can cause adverse flavor and color changes (Wood et al., 2003).

In Australia, the use of feedlotting is restricted mainly to supply the niche of the USA's lamb market. For example, in some states, like Western Australian, lamb feedlots have increased, and most of the research has been concentrated on improving productivity, reducing feeding costs, and increasing feed conversion (Bowen et al., 2006). Profound research has been done in Australia characterizing the fatty acid profile of lamb under grazing conditions, and manipulating them to produce healthy lamb (Pethick et al., 2006).

In Uruguay, restricted grain supplementation on fattening lambs under grazing conditions is one of the technology options available to increase farm production and profitability in particular under high stocking rates or restricted quantity and quality forage conditions (Montossi et al., 2003). Under restricted pasture conditions, supplementation also improved lamb carcass and meat quality (Montossi et al., 2007, 2003) and contributes to augment the competiveness of lamb production business (Montossi, Ayala, & Díaz, 2008). In this context and looking for opportunities to improve Uruguayan lamb profitability and lamb meat acceptability in the European market, different combinations of pasture:concentrate feeding regimes on fatty acid composition, sensory attributes and consumer acceptance and perceptions have been studied, which have been summarized by Montossi and Sañudo (2007b). These studies have shown that the inclusion of certain amounts of concentrates in the diet of grazing lambs on improved pastures, could improve animal performance, carcass and meat quality, sensory attributes, and consumer acceptance without changing the fatty acid composition compared with the grass-fed animals. Later, these results were confirmed by Montossi et al. (2009). Therefore, it is possible to use restricted grain supplementation to promote simultaneously lamb productivity and efficiency and healthy meat under grazing conditions.

Finally, in addition to the importance of consumer healthier meat in human lives, it is also important to include another concept where red meat contributes to food security. This is related to availability of enough quantities of food, access of people to adequate resources, stability of food supply and utilization of food by appropriate diet, clean water and health care to achieve nutritional well-being status. Livestock productions add to the food supply beyond what crops can provide (Food and Agriculture Organization of the United Nations (FAO), 2011).

### 2.4. Production systems and animal welfare

As it was previously mentioned in this article, sheep production systems vary worldwide from highly extensive to very intensive systems.

Some welfare constraints exist in all of them, but many others have different importance depending on the intensification level achieved. Advantages and disadvantages concerning the welfare of sheep have been reported for both extensive and intensive farming systems (Fitzpatrick, Scott, & Nolan, 2006; Sevi, Casamassima, Pulina, & Pazzona, 2009).

Under extensive production systems, animals are free to move within a habitat that allows them to best perform their physiological and behavioral functions. However, grazing can also adversely affect animal well-being, due to seasonal fluctuations of herbage amount and quality; consequently, grazing animals are usually subjected to a temporary nutritional stress (Nardone, Zervas, & Ronchi, 2004; Sevi et al., 2009). Therefore, grazing animals in extensive rearing can face nutritional imbalance during this period of the year, with the alteration of rumen fermentation and protein synthesis, which compromises their well-being and negatively influences productivity. If the nutritional stress occurs during the mating season, it can also reduce sheep fertility (Rassu, Enne, Ligios, & Molle, 2004). High yielding dairy ewes farmed under semi-intensive conditions can experience nutritional unbalance as well (Sevi et al., 2009) or very intensive production system is not proper nutritional and husbandry practices are applied. In particular, sward surface height and green leaf mass have been recognized as the factors playing a major role on ingestive behavior, herbage intake and production performance of sheep and goats (Penning, Parsons, Orr, & Treacher, 1991). Field trials suggest that a sward surface height close to 60 mm and a green leaf mass of 1500 to 2000 kg/ha can improve intake, welfare and performance of sheep (Orr, Parsons, Penning, & Treacher, 1990) under temperate grazing conditions on improved pastures.

Improved pastures and proper use of them, and restricted grain supplementation not only increase production, lamb carcass and meat quality as it was previously mentioned in this paper, but also improve animal welfare. These, among other technologies for mitigate nutritional stress, are available for extensive systems (e.g. automatization, genetic improvement).

Lamb mortality has both economic and animal welfare implications in sheep production, especially in extensive systems where it will be around 20–25%. Strategies to improve lamb survival have been evaluated for a long time, including nutritional management of the lambing ewe, timing of reproduction selection of ewes for improved mothering ability and shearing management. By careful shepherding of the ewe from conception to delivery, and the perinatal care of the new born lamb, many deaths can be avoided.

A whole raft of improved technology, improved management and knowledge has led to the ability to increase both number of lambs born and number of lambs surviving within extensive farming systems. Improved nutrition at mating enhances potential lamb numbers during mating (Gunn, 1983), improved nutrition close to lambing enhances colostrum production and lactation (Treacher, 1983) and enable greater care by the shepherd. Both these factors will have impacts on the potential for survival in the neonatal period. The effects of supplementary feeding during the middle and late pregnancy period have been widely studied in both intensive and extensive situations. The links between nutrition of the ewe and lamb birthweight and between birthweights and lamb survival have also been very clearly demonstrated (Mellor, 1983). This is further mediated by effects on the physiology of the new born lamb which in turn affect the capacity to withstand harsher environments (Rowan, 1992). Calostrum quality, quantity and milk production, as affected by pregnancy nutrition (Banchero, Quintans, Lindsay, & Milton, 2009; Banchero et al., 2007; Robinson, McDonald, McHattie, & Pennie, 1978) also strongly influence immediate survival and subsequent performance. Different shearing techniques are also studied in order to improve lamb survival (Banchero, Vázquez, Montossi, de Barbieri, & Quintans, 2010; Sphor, Banchero, Correa, Osorio, & Quintans, 2011).

In many flocks, the number of multiple pregnancies has increased. Twins typically have a higher death rate than singles (Purser & Young, 1959). Increases in twinning rates could conceivably lead to increased overall mortality unless management is changed. Better nutrition, fitted to the needs of the pregnant twin bearing ewe, together with the lambing management should lead to major improvements in lamb survival, and probably in ewe survival.

The quality of maternal care received by lambs can be influenced by a range of factors. Several factors can influence mother–young relationships in sheep (Lindsay, Nowak, Gede Putu, & McNeill, 1990). It has been shown in both extensive (Alexander et al., 1983) and intensive (Poindron, Raksyani, Orgeur, & Le Neindre, 1984) rearing conditions that maternal behavior after parturition varies according to breed. Differences in reactivity between breeds have also been observed and related to maternal behavior (Gede Putu, 1990), including the capacity of the mother to cope with the stress of parturition and isolation from the flock (Blache & Ferguson, 2005). The use of prolific sheep breeds has been widely advocated to increase lamb production, and in intensive rearing systems has been successful, bringing with it financial gain. Greater emphasis will be placed on the ability of animals to adapt to an environment and on their behavioral response. It will be particularly important to achieve harmonious establishment of mother–young relationships. Animals will also have to be accustomed to the presence of human beings even if the contact periods are only short, because adverse responses can lead to stress. In addition, human intervention can influence maternal behavior and cause ewes to abandon their young and thereby result in high mortality rates (Le Neindre, Boivin, & Boissy, 1996). It is suggested that there is knowledge and technology available to ensure that lamb mortality, as one indicator of welfare linked to production and profitability, can be kept down to levels that are comparable with good lowland flocks (Waterhouse, 1996).

Predation is a threat to sheep welfare and thereby the profitability of sheep farming. Sheep have very little ability to defend themselves, even when compared with other prey species kept as livestock. Even if sheep are not directly bitten or survive an attack, they may die from panic or from injuries sustained (Simmons & Ekarius, 2001). However, the impact of predation varies dramatically with region. In Africa, Australia, the Americas, and parts of Europe and Asia predators can be a serious problem. Proper strategies should be implemented depending on each context, considering predator's welfare and public and consumers concerns.

Many studies have focused on the human and animal relationship, which has often been overlooked in common rearing practices, but it has a relevant impact on sheep welfare and production performance. Research has shown that human–animal interactions can impose some substantial limitations on animal welfare in the livestock industries and there is a strong case for using stockperson training courses that not only target technical knowledge and skills but also target the attitudes and behavior of the stockperson (Hemsworth & Coleman, 1998). Changes in rearing systems considerably modify these relationships. An acceptable level of tameness can be achieved by certain adjustments to the management system, in particular a scheduled series of short periods of contact with human beings. In extensive husbandry conditions, short periods of contact improve cattle–human relationships particularly if handling occurs a few weeks after birth and just after weaning (Le Neindre et al., 1996). Markowitz, Dally, Gursky, and Price (1998) reported that human feeding and handling of lambs within the first 10 days of their lives resulted in increased affinity for humans later in life. Sheep are also able to differentiate between their handler and a stranger, to the point that the presence of their handler has a calming effect in stressful conditions (Boivin, Nowak, Le Neindre, & Tournadre, 1997). Human education and training is the most valuable investment to improve animal welfare (Hemsworth & Coleman, 1998).

Castration and tail docking are procedures used in several species and they are of particular relevance to welfare studies. Although further research is required on the assessment of pain associated with both procedures, there is enough evidence for pain and distress associated with the different methods of castration (rubber ring, bloodless and surgical) and also for tail docking (rubber ring, bloodless, surgical removal and

hot iron). Therefore, legislation and recommendations vary among countries, but the scientific community agrees that independently form the technique applied, they should be performed only when they are necessary, early in animal life and with the use of pain mitigates. Johnson, Sylvester, and Stafford (2009) demonstrated that very young lambs have a reduced cerebrum-cortical response to castration than their older counterparts and it has been assumed that they perceive less pain. The most common practice in extensive conditions is to perform both procedures at the same day (castration and tail docking), but considering that stress is additive, is strongly advised to separate painful procedures.

The rubber ring method of castration maintains popularity despite the fact that it is one of the more painful methods, depending on lamb age. Several studies were conducted to determine ways of reducing the pain accompanying this procedure. The use of an epidural anesthetic was ineffective in reducing the pain induced by rubber ring castration (Scott, Dun, Penny, Strachan, & Keeling, 1996). However, the use of a local anesthetic in conjunction with the ring method was effective in reducing pain (Kent, Molony, & Graham, 1998). These authors also found that combining the rubber ring and bloodless castrator (clamp or burdizzo) methods resulted in a reduction in pain compared to the ring method alone. This was confirmed by Thornton and Waterman-Pearson (1999) who compared the ring and combined methods with surgical castration. In terms of overall pain and cortisol response, the combined ring and clamp method was the least harmful when no anesthetic was used. A local anesthetic was completely effective in eliminating the reactions to ring and combined castration, but not for the surgical method. A general anesthetic was effective for the surgical method. The conclusion to be drawn from these studies is that the use of a combined method is the least stressful of those studied, and that it can be further improved with the use of a local anesthetic. Two other studies examined management factors associated with either ring or bloodless castrator methods. In one, Kent, Molony, Jackson, and Hosie (1999) concluded that the ring should be used for small lambs. When used for lambs at 28 or 42 days of age there were more severe and larger lesions than when used on 2-day-old lambs. A survey of problems encountered with the use of the bloodless castrator indicated that hemorrhage and infection were common (Hosie, Carruthers, & Sheppard, 1996). It was recommended that only castrators designed for use on lambs should be applied, that the instrument should be properly maintained and stored, and that stockpersons should be trained in it use.

Although the use of a heated cautery iron produces the least changes in behavior and cortisol levels (Graham, Kent, & Molony, 1997), it is not the preferred method of tail-docking due to the incidence of chronic infections. Like castration, studies have examined ways to reduce the pain associated with the application of rubber ring method. Combining the ring and burdizzo crush reduces the pain compared with the ring method alone. An injection of a local anesthetic at the ring site is also effective (Graham et al., 1997). Following an additional study, these same researchers concluded that the use of a local anesthetic, either injected or needleless, was more effective in reducing pain than the application of the burdizzo clamp alone followed by the application of the rubber ring. The operators must be trained and competent.

Cutaneous myiosis (flystrike) is a significant welfare and production disease for Australian Merino sheep, initiated by the oviposition in the sheep's tissues of the blowfly *Lucillia cuprina* (Diptera: Calliphoridae) (Taylor, 2012; Wall, 2012). For many sheep farmers, particularly those in the so-called grazing areas, unsuitable for cropping, where fine-wool merino sheep dominate, an important strategy to manage myiosis risk, (in use for 80 years) has been the "mulesing" operation (Beveridge, 1984). The procedure involves surgical modification of the breech area of young sheep to remove excessive perineal skin and 'wrinkle', reducing the accumulation of breech moisture and providing a life-long decrease in the risk of myiosis. Mulesing usually accompanies "lamb marking", routinely performed to improve health management at the age of 6–10 weeks (Windsor & Lomax, 2012). Pressure by welfare activists on international wool buyers, with threatened boycotts, resulted in a proposal by Australian Wool Innovations to cease mulesing by 2010, if suitable alternatives could be found (Sneddon & Rollin, 2010). This proposal proved unachievable, although significant research progress in managing the issue has been made. This has proven unachievable, although significant research on alternatives to mulesing has occurred, as recently reviewed (Fisher, 2011). An integrated pest management approach to myiosis control involves crutching (shearing of breech wool prior to periods of moisture accumulation, such as lambing), timing of shearing (removal of all wool prior to fly-wave activity), chemical protection (jetting or dipping with acaricides) and genetic selection against the risk factors of breech "wrinkle" and "dag". Where necessary and for a short to medium term period, until wrinkle and dag can be genetically minimized, the use of surgical alteration of breech conformation to reduce the propensity for accumulation of moisture in excessive skin of the tail and perineum is advisable. Currently, mulesing is continued as a necessary part of an integrated management program for myiosis in many wool-producing sheep flocks. However, major modifications of the manner in which the operation has been performed, have occurred, including accreditation of mulesing contractors and, most importantly, the introduction of pain management at mulesing (Windsor & Lomax, 2012).

There are many alternatives to intensify sheep production. These include feeding pads, feedlots and housing. Intensive systems require additional skills of stockmanship and management. The environment, including surfaces and flooring, high stock density and the provision of concentrated feeds can create challenges to animal health and welfare, which may compromise animals or amplify the effect of any existing problem. While semi-intensive and intensive farming conditions can ensure that some of the animals' needs are more easily or more efficiently met (e.g. sheep are generally preserved from hunger and thirst, and could be sheltered from climatic extremes), and animals live in a very predictable and less motivating environment. Increased stock density may be associated with restrictions on normal behavior patterns, increased risk of aggressive interactions between animals and increased risk of transmission of infectious diseases. Frequent monitoring and good stockmanship are therefore required. In semi-intensive rearing much attention must be given to micro-environment control, and to choice of proper house structures, material and design, in order to avoid crowding, abnormal and aggressive behavior, increased ambient pollution, and poor udder health (Sevi et al., 2009).

Confined rearing is usually characterized by high stocking density and prolonged feces accumulation in sheep and goat houses. Therefore, adequate space allowance, careful litter management and scrupulous monitoring of the micro-climatic factors (in terms of temperature, relative humidity and air quality) are crucial aspects in sheep and goat housing. In any case, it is fundamental to understand that maintenance of good hygiene conditions, associated with correct dimensioning of structural parameters and adoption of proper management practices, is important in either type of system. Several research works have been done about these issues. For space allowance and air quality, see Chiumenti (1987), Dickson and Stephenson (1979), and Loynes (1983). For stocking density, see Sevi, Massa, Annicchiarico, Dell'Aquila, and Muscio (1999). For airspace, see Hartung (1989), Sevi et al. (2001), Sevi, Albenzio, Muscio, Casamassima, and Centoducati (2003), and Wathes, Jones, and Webster (1983). For ventilation, see Albenzio et al. (2004), Albenzio et al. (2005), Sevi (2005), Sevi et al. (2002), Sevi, Taibi, Albenzio, Annicchiarico, et al. (2003), and Sevi, Taibi, Albenzio, Caroprese, et al. (2003).

Housing system can also affect the nutritional status of farmed animals. Indeed, farmers have to adjust feeding rations taking into account the level of activity related to different housing systems in order to prevent transient conditions of nutritional stress. Intensive systems should work hard in demonstrating their animal welfare advantages and in releasing the most important limitations associated to their production systems, always considering scientific results and consumer concerns.

Animal welfare and public attitudes toward it must be considered wherever the sustainability of an animal production system is evaluated (Broom, 2010). Enhanced welfare of farmed animals can be achieved through improvements in one of three on-farm aspects: animal environment/management procedures, stock person attitudes or adaptability of animals in their production environments. Many different sorts of measurements on animal welfare, including health, behavior, physiology and production might have to be made and integrated in order to asses animal welfare status and to answer all the questions related to precise definitions of particular problems and challenges that animal are facing in different situations and production systems (del Campo, 2010). Simple extrapolation of scientific information and methodologies developed for intensive systems to extensive conditions is incorrect and probably biased, and special attention has to be considered by the scientific community in this regard.

It is important to highlight that perception differences about the importance of different management practices related to animal welfare, could be find along the meat quality chain. Therefore, balancing of short term (pain related) welfare issues and long term issues of greater economic impact, is a communication challenge for different actors involved in meat consumption, including scientists (Phillips, Wojciechowska, Meng, & Cross, 2009).

## 3. Sheep meat production and consumption: sustainability, intensification, and consumer's preferences, beliefs and values

### 3.1. The influence of religion on sheep meat acceptance for consumption

Religion is an aspect which is related with consumers' food choice as well as lifestyle, culture, diet or health (Nakyinsige, Man, & Sazili, 2012). This food choice is also related with food restrictions or prohibitions. Christianity only establishes some food restrictions during some periods of time, such as Lent and Easter time. Other religions, like Hinduism or Buddhism do not allow pork and beef consumption and Judaism and Islamism do not allow pork, in all the cases, because they are not considered clean meat. Moreover, all the meat consumed for followers of the Judaism religion must be kosher and those of the Islamism religion must be Halal (Dindyal & Dindyal, 2003).

Halal meat or "permitted" meat is a product attribute related with their nature, origin and processing method and it is similar to organic meat or meat produced considering animal welfare or sustainable issues (Bonne & Verbeke, 2008a) and implied meat that is permissible, lawful and clean (Agriculture and Agri-Food Canada [AAFC], 2011).

The importance of the Islamism religion in lamb consumption can be seen, for instance, because during pilgrimage (Hajj) to Mecca, it is required to all the participants to sacrifice a lamb or mutton, and this supposes around 2 million lambs or mutton annually (Faris, 2003), which do not suppose a health problem because sacrifice is done with proxy (Ahmed, Arabi, & Memish, 2006). This annual consumption also increases because all other Muslims who could not go to the pilgrimage might make a sacrifice at the same time period every year. Furthermore, in some celebrations, like the feast of the sacrifice (Eidul-Adha) and the birth of a new baby, it is also recommended to Muslims to sacrifice a lamb, goat or mutton (Faris, 2003).

Muslims consume lamb for religious purposes, but this is also present in their current diet. Consequently, lamb consumption is very important within Muslim population which in 2010 represented 23.4% of the world population and it is expected to increase up to 26.4% in 2030. It is found mainly in Asia–Pacific (62%), middle east-north Africa (16%) and Sub-Saharan Africa (15%). There are also 2.7% of Muslims in Europe and 0.3% in America (Pew Research Center Forum on Religion & Public Life, 2011).

It is important to know the amount of immigrant Muslims that, far from their country of origin, follow religious directresses regarding Halal meat. It has been reported to be 75% in US (Hussaini, 1993) and 84% in France (Bergeaud-Blackler & Bonne, 2007).

In 2011, in US, Halal consumers spent $15 billion on Halal food and related services (Islamic Food and Nutrition Council of America. IFANCA, 2012) and France, with the largest population of Muslims in Europe (Lever & Miele, 2012), has a Halal market worth $7.6 billion per year (Agriculture and Agri-Food Canada, 2011). In the UK, Muslims make up just 5% of the population and they consume an estimated 20% of all lamb and mutton produced (The Muslims Council of Britain, 2013). In the European Union, where Muslim population was estimated in more than 44 million individuals in 2010, the potential market for the Halal foods is growing fast (Lever & Miele, 2012) and, according to this, in Europe there are companies with and important production and exportation of Halal food (Agriculture and Agri-Food Canada, 2011).

Thus, lamb produced under Halal guidelines has an important potential in the European and American market and that's why Halal food market has grown quickly over the past decade, and is now estimated in $632 billion annually in a global scale (Agriculture and Agri-Food Canada, 2011). Moreover, this would be even more important if further studies confirmed that young generations of Muslims are more interested in Halal than their parents (Bergeaud-Blackler & Evans, 2010).

Muslim consumers are concerned about food safety and quality as well as the Halal status of the meat (Agriculture and Agri-Food Canada, 2011; Bonne & Verbeke, 2008b). In Europe, there is a perception that Halal consumers are safer and more ethical (Agriculture and Agri-Food Canada, 2011) and in general, Muslims consume Halal meat because they related it with healthy meat (Bonne, Vermeir, & Verbeke, 2009). Nevertheless, the same authors distinguished between different attitudes towards the health status of Halal meat depending on the acculturated level and Muslim self-identity degree.

It is important to study ways to assure the Halal authenticity of meat and meat products labeled as Halal (see review of Nakyinsige et al., 2012) as well as why there are different organizations responsible of control and assure Halal food products which follow different assurance standards guidelines for Halal (Lever & Miele, 2012; van der Spiegel et al., 2012). This control, together with the implementation of a Hazard Analysis Critical Control Point (HACCP) system for Halal control points can assure Halal meat quality (Bonne & Verbeke, 2008a) and contributes to reduce Halal quality uncertainty among consumers (Bonne & Verbeke, 2008b). Nevertheless, consumers can be segmented depending on their health and safety perceptions of Halal meat, trust in Halal meat status and control, and depending on their opinion of who must perform it (Bonne & Verbeke, 2008b). In general, focus group studies performed in Bordeaux, Cardiff, Renaix and Istanbul, showed that Halal consumers preferred to purchase Halal meat in Islamic butchers that they perceived them as more secure and confident of Halal status, and to support Muslim community, but in Amsterdam they preferred Halal meat from supermarkets because they can find ready-meals (Bergeaud-Blackler & Evans, 2010). This can be used in marketing strategies to open the market of Halal lamb meat.

### 3.2. Genetically modified (GM) animals and consumer attitudes

The birth of Dolly sheep (July 5, 1996) was one of the most remarkable disruptive events in the history of science. She was the first mammal to be cloned from an adult somatic cell, using the process of nuclear transfer (McLaren, 2000; Wilmut, Schnieke, McWhir, Kind, & Campbell, 1997). Since this event where Dolly was created without the need of male cells to fertilize the egg and mature it, the world has not been the same, and the debate of using GM for modern livestock production and modern life is still going on.

It is expected that soon a GM salmon will be released to the general public in USA. This will be maybe the first GM animal to enter into the food chain worldwide. The mentioned event probably opens strongly the debate again about the use of GM for mankind (Fahrenkrug et al., 2010; Váquez-Salat, Salter, Smets, & Houdebine, 2012).

The use and progress of transgenic technology in livestock production will be profoundly impacted by two recent developments: 1) the ability to isolate and maintain embryonic and somatic cells directly from embryos, fetus and adults in vivo, and 2) the ability to use these embryonic and somatic cells as nuclei donors cloning strategies. These have so many advantages which could not be applied by using the current pronuclear injections of DNA (Wheeler, Walters, & Clark, 2003). In addition, the costs of transgenic production have been reduced by technology advance.

Váquez-Salat et al. (2012) highlighted that the most common applications of GM in animals are: a) basic research to generate new therapeutics with numerous applications in the market, and restricted to the laboratory work and used mainly with rodents, rabbits and pigs, b) xenotransplantation of cell, tissue, or organs from one species to another. For example, this will be use in GM pigs (close to human genome) to facilitate organ transplantation in humans, with nearly 5 year horizon to reach the market, c) bioreactors to generate GM animals for producing recombinant pharmaceutical proteins in their milk (goats, rabbits, cows, and pigs), with two commercial products already available in the market, d) animal productivity where most of GM animals have modified to increase productivity, disease resistance, quality, etc. (mainly on meat, fiber, and milk), where the first transgenic animal (salmon) is very close to be available in the marketplace, and finally e) pet industry, where several GM animals have development for human recreation purposes, with one product (fish with fluorescent gene to glow in the dark under ultra violet light) commercialized in the market.

Base of the review of GM animal applications available to be released in the food and pharmaceutical sectors (Váquez-Salat et al., 2012), it can be seen that only 1 out of 15 transgenic traits could have direct application to the sheep industry (resistance to prion diseases). Fahrenkrug et al. (2010) also reviewed current and envisioned genetically engineered livestock applications to agriculture, where again just 2 applications (Visna virus resistance and ovulation rate) out of 32, could have specific use for the sheep industry. However, other GM applications proved in other species can also be use for sheep in the future (e.g. enhance growth rate, modified some aspects of the meat quality).

Around the world the genetic modification of animals and plants by transgenic remains a controversial issue. However, several specialists in this field mentioned that the public resistance to the use of GM will be higher in animals rather in plants. Some issues related to moral and ethical aspects of our modern society have been raised by governments, animal protection groups, and media against the use of GM animals, particularly in the food chain (Knight, 2009; Váquez-Salat et al., 2012).

The negative perception of consumer against genetically modified organism (GMO) mainly felt into the combination of environmental, economy, safety, and ethics issues (Knight, 2009). Most of the negative perceptions are associated (e.g. Blasco, 2008; Frewer, Howard, & Shepherd, 1997; Pascalev, 2003; Tsourgiannis, Karasavvoglou, & Florou, 2011) with: a) human health (e.g. allergies), b) environmental risks (particularly on the long-term), c) ethical (e.g. animal welfare), d) cultural values, e) unnatural and immoral issues, and f) religious reasons (e.g. pig genes in foods used by the Muslim community).

Among the beneficial factors argued by the supporters of the use of GM animals, the following can be highlighted: a) technology solutions for food and water scarcity, b) improvements in human and animal health, c) lowering of the cost for production and industrialize goods, d) maintained or improved environmental sustainability, e) increased productivity and efficiency along the food supply chain, and f) promoted animal welfare (e.g. avoid of castration) (Fahrenkrug et al., 2010; Knight, 2009; Nelson, 2001).

However, Blasco (2008), reviewing the literature about the possibility of using transgenic animals in agriculture, stated that “it has been said that this is a field in which there are more reviews about the possible use and future of transgenesis than actual papers with data”.

Christoph, Bruhn, and Rossen (2008) demonstrated that German consumers do not have the same perceptions about all animal-related potential influence of the use of GM in their society. For example, they are more prone to the use of GM animals to human medicine (e.g. GM insulin for diabetes treatment) and to food production for enhancing nutrition (e.g. vitamins) in developing countries. However, in general terms, this study also showed the negative perception of German consumers about the acceptability of GM (animals and plants) for food production. Furthermore, even with the appearance of novel studies which could show no risk to human for using these products, some consumers will not eat GM foods, given their strong negative attitude against to GM products. This could reflect the lack of trust towards the authorities and the control procedures. Mucci and Hough (2003) also demonstrated negative perceptions towards the consumption of GM foods in Argentine consumers, in particular associated with human and environmental potential risks, with no confidence in the control of them by the government agencies and the private sector.

In any case the humanity has been eating beef, milk, poultry products and so on, even during centuries, that include millions and millions of genes (with their respective mutations) of bovine and not specific concerns has been originated.

Tsourgiannis et al. (2011) showed the negative perceptions for consuming GM foods in a group of Greek consumers. Based on these results, the authors suggested and promoted the use of labeling and certification for GM free foods to differentiate and increase the competitiveness of local products, and being more competitive in this niche market against imported products (conventional). This is particularly important in EU, where there is no obligation to label animal products as it is the case for the vegetal ones. However, Schilter and Cosntable (2002) argued that traceability and labeling are important developments in the GM food regulation arena in the European market. However, these authors also said that labeling maybe counter-productive, increasing confusion between consumers about the safety of GMOs, promoting unfounded increase aversions against them.

In relation to GM issue, the USA and EU have had a very different approach to this topic in almost all the segments of the food chain (academia, government, private sector, media, environmental and animal welfare groups and consumers) (Knight, 2009; Rowland, 2002; Váquez-Salat et al., 2012). There is a long and antagonist debate between the USA and EU related to the development, control and use of GM animal products by the society. This opposition is expected to be prolonged through the time. An important factor to be considered is the key role that China could play in this dilemma, particularly taking consideration the advance of this technology in this country and the wide acceptance of GM foods among Chinese consumers (Zhang, Huang, Qiu, & Huang, 2010).

The destiny of what happen with GM food production, importation, exportation, consumption could be an important factor to be considered by the sheep industry around the world. In this sense, China has the biggest sheep population of the world, whereas USA and EU are between the top 5 importing sheep meat markets. The future competiveness of sheep industry will be surely shaped by this issue. The balance between negative and positive factors affecting production and the worldwide acceptance of GM animals on the sheep industry remains to be seen. In any case, some real and objective works, analyzing the implications of the GM on the environment and food chain, need to be done.

### 3.3. Food safety and consumer preferences

Consumer perceptions are dynamics, and there are often differences between what consumers perceive and their behavior. The last two decades have brought major behavioral changes to consumers. Among the world's food industries, the meat industry is the one facing most public negativity, especially due to the association of meat consumption with certain risks to human health (heart disease) and secondly safety scares. The main risks related to meat consumption as perceived by consumers

are chemical residues of growth hormones and antibiotics, high fat content and the related hazards of increased cholesterol, microbial infections (e.g. *Salmonella*, *Escherichia coli*), dioxins, the use of genetic modification in the production of animal feed as well as BSE.

As an example of this risk and related to the prevalence of specific pathogens in foods, Desmarchelier, Fegan, Smale, and Small (2007) reported that the most studied group of human pathogens are the enterohaemorrhagic *E. coli* (EHEC). In a survey of Australian retail lamb cuts for shiga toxin producing *E. coli* (STEC) no O157, Barlow, Gobius, and Desmarchelier (2006) detected STEC in 40% of lamb samples.

The increased awareness of food safety, as well as changes in dietary and consumption patterns have attracted interest in studying fresh meat consumption preferences (Bernabéu & Tendero, 2005; Grunert, 2005). Various studies have focused on consumer behaviors related to lamb meat. Past studies have found that attributes such as quality and safety perceptions, and health concerns (McEachern & Willock, 2004; Rimal, 2005) influenced consumer choices. Under normal conditions, consumers are not aware about product safety, but fears are present in a latent state, and the perceived safety is critical. Richardson, MacFie, and Shepherd (1994) found that eliminating microorganisms from meat was a safeguard for which most of the consumers pay a premium. A second important factor is the fears for residues, especially antibiotics and hormones. For 80% of the French interviewed citizens, the perceived safety (free of micro-organisms) was classified second in a 5 criteria rate for meat quality, and almost 24% of the British interviewed citizens declared to reduce the meat consumption due to the fear of residues (Richardson et al., 1994). In other study, Corcoran et al. (2001), describing the factors which influence consumption in a consumer perception study, mentioned that participants were worried about security issues in meat consumption. For example, the British were more concerned about BSE and *E. coli*, and the French about contents of hormones and antibiotics.

In the report of the Special Eurobarometer 354 for Food-related risks (2010), evaluating the public perception of food and food-related risks, showed that food safety (37%) was less commonly associated with food and eating quality. Also in this study, grouping the risks into three categories according to the "very worried" responses, it was reported that the second issue which EU citizens (70%) feel the most worried about is residues presence (like antibiotics or hormones) in meats.

This awareness of food-related safety issues among today's food consumers is driving the demand for more information about the vertical food supply chain and specifically the origin and handling of food products generated and consumed throughout the world (Smith et al., 2005). Consumers are thus starting to look for signs and certification that guarantee safety and reassure them.

To reduce the burden of microbial meat borne illness and chemical residues is important to develop a food safety management systems based on risk analysis. HACCP provides the basis for the food safety management system. The seven essential steps for HACCP are outlined by Codex Alimentarius Commission (Codex Alimentarius Commission & Committee on Food Hygiene, 1991) and cover all stages of food chain (from production to retail) (Troy & Kerry, 2010). Meat processors are required to put into place approved HACCP based process management systems and for export they must also comply with the requirement of the importing country. However, a whole of meat chain approach should incorporate identification and traceability being meaningful to consumers in terms of its benefits such as safety and quality. In the meat area, there is a need for fast and reliable systems to enable traceability along the full supply chain to provide safe and high quality food for the consumer.

Traceability is defined as the ability to maintain a credible custody of identification for animals through various steps within the food chain from the farm to the retailer. Traceability of a food product consists in developing an information trail (Smith et al., 2005). It guarantees the recall of food if it is demanded. In the meat sector, traceability offers the ability to identify an animal, trace its movement throughout its life and trace the meat products of this animal to the final consumer (Verbeke, 2003). Regulatory agencies established the implementation and application of traceability systems for meat products from the production level through to the consumer throughout the entire supply chain. Uruguay is a good example of the implementation and application of one of these systems (Instituto Interamericano de Cooperación para la Agricultura. IICA, 2009).

Coff, Korthals, and Barling (2008) defined the objectives of traceability in food: a) risk management and food safety, b) control and verification, c) supply chain management and efficiency, d) quality assurance of products, and e) information and communication to the consumer.

Du Plessis and du Rand (2012) reported that price is known as the most determining factor in consumer's purchasing decision. A higher price can sometimes symbolize better quality or safety of the product for the consumers. Safety is the second most important attribute after price and it was found effective in the purchasing decision at 23.1%. These authors using utility values for safety showed that consumers preferred safety lamb through certification, followed by safety through place of purchase and then safety through labeling/branding.

Market access requirements continue to be a challenge for meat export countries. Galyean, Ponce, and Schutz (2011) noted that emphasis on economic efficiency in meat production systems, associated with efforts to reduce emissions and maintain the highest animal welfare and food safety standards will ensure the long-term future of the North American beef industry. In addition, public concern for safety has induced greater concern for animal traceability (Galyean et al., 2011). Safety, traceability and product quality are also the main drivers of the beef industry in Brazil (Millen, Pacheco, Meyer, Mazza-Rodrigues, & De Beni-Arrigoni, 2011). In Argentina, healthiness and traceability are considered important drivers to sustain animal production (Arelovich, Bravo, & Martínez, 2011). For other countries such as Australia, New Zealand and Uruguay, research priorities for meat are focused on safety and healthiness, as production systems have to be ethical from animal welfare and environmental points, all of them are critical to maintain a competitive position in the marketplace (Desmarchelier et al., 2007; Montossi & Brito, 2012).

### 3.4. Production system effect on consumer acceptability of lamb meat

Sheep production systems are very variable between and within countries because they are related with different environmental conditions and agricultural practices (Sañudo et al., 2007). Preferences of lamb by consumers are affected by production systems, given that production systems are linked with the sensory characteristics of the lamb meat, and associated furthermore with cultural aspects or consumption habits, consumer attitudes, beliefs, feelings and moral considerations. One of the most important factors related with production systems is animal feeding. Sepúlveda, Maza, and Pardos (2011) found that both, consumers and producers, consider animal feeding as the most important production aspect related with lamb quality.

The type of feeding affects the composition of lamb meat and, consequently its sensory characteristics (see reviews of Duckett & Kuber, 2001; Melton, 1990; Priolo, Micol, & Agabriel, 2001; Schreurs, Lane, Tavendale, Barry, & McNabb, 2008). Differences between different grass-feeding regimes have been reported (ÅdnØy et al., 2006; Dervishi, Joy, Alvarez-Rodriguez, Serrano, & Calvo, 2011; Fraser, Speijers, Theobald, Fychan, & Jones, 2004; Lourenço, Van Ranst, De Smet, Raes, & Fievez, 2007; Park, Corbett, & Furnival, 1972) as well as different concentrate feeding regimes (Ponnampalam, Sinclair, Egan, Ferrier, & Leury, 2002; Ray, Kromann, & Cosma, 1975), or by other intrinsic or extrinsic characteristics. Besides that, important differences in flavor, odor and texture of lamb meat can be found in lamb from grass-feeding compared with those from concentrate feeding, which in turn affected consumer acceptability of lamb meat.

In general, grass-fed lamb has been reported to have higher skatole content and off-flavors (Resconi, Campo, Font i Furnols, Montossi, & Sañudo, 2009; Young, Lane, Priolo, & Fraser, 2002), higher intense "mutton" odor and flavor (Sañudo et al., 1998; Wood & Fisher, 1990)

and more rancid, acid or livery flavor (Priolo, Micol, Agabriel, Prache, & Dransfield, 2002; Resconi et al., 2009) than concentrated-fed lamb. On the other hand, concentrated-fed lamb has been reported to have higher tenderness and more favorable lamb odor and flavor (Priolo et al., 2002; Resconi et al., 2009; San Julián, Luzardo, Brito, & Montossi, 2007). These sensory differences are due to different lamb compounds presented in the fresh meat or generated during cooking. The quantity and quality of lamb fat has an important role in the sensory characteristics of the meat. In this sense, concentrate-fed lamb has higher intramuscular fat content (Díaz et al., 2002; Priolo et al., 2002; San Julián et al., 2007; Schönfeldt, Naudé, Bok, Van Heerden, & Sowden, 1993; Smith, Dutson, Hostetler, & Carpenter, 1976) than pasture-fed lamb. The fatty acid profile also is different depending on the production systems. In general, pasture-fed lambs have higher conjugated linoleic acid (CLA) and α-linolenic acid (Aurousseau, Bauchart, Calichon, Micol, & Priolo, 2004; Cañeque, De la Fuente, Díaz, & Álvarez, 2007; Enser et al., 1998; Kemp, Mahyuddin, Ely, Fox, & Moody, 1981). The oxidation of α-linolenic has been related with the pastoral flavor (Young & Baumeister, 1999). Moreover, grass-fed lamb has lower total PUFA (Kemp et al., 1981), higher n − 3 PUFA and lower n − 6/n − 3 PUFA ratio (Enser et al., 1998; Resconi et al., 2009), which demonstrated to promote human health (McAffee et al., 2011). These differences in fat composition of lamb fed with different regimens affect consumers' sensory acceptability (Dransfield et al., 2000; Font i Furnols et al., 2006, 2009; Joy et al., 2012; Sañudo et al., 2007).

Moreover, cultural background or consumption habits also play an important role in this acceptability (Alfonso, Sañudo, Pardos, Fisher, & Sierra, 2000; Fisher et al., 2000; Font i Furnols et al., 2009, 2006; Sañudo et al., 1998, 2007), explaining different consumer attitudes towards lamb meat, which may affect their purchasing decisions (Sañudo et al., 2007; Verbeke & Vackier, 2004). This can be clearly seen in the results of a large scale EU study (FAIR3-CT-1768 — OVAX project) to assess the effect of the type of lamb on different consumer acceptability by home testing test assessment. Beside the differences found in consumer scores between countries, influenced probably by their degree of lamb consumption or their consideration to lamb meat, most of the total variability (86.2%) in lamb scores was explained by production system involved in each type of lamb produced. In this sense, lambs reared on concentrate or milk, with more less intense flavor, were clearly associated with the Mediterranean countries, whereas the grass-fed lambs, with more intense flavor, were associated with the Northern countries (Alfonso et al., 2000; Sañudo et al., 2007). This can explain why some consumers are not used to the "muttony" or lamb flavor presented on grass-fed lambs and prefer meat from lamb concentrate-feed and the opposite occurs to Font i Furnols et al. (2006). This project also showed that lambs one year old (managed under the transhumance system) were clearly separated, since it is a type of local lamb that most consumers were not used to consume. Then, results suggest a link between assessments of a given lamb type and consumers' culinary background, past experiences and sensory habit, showed previously by taste panels (Fisher et al., 2000; Sañudo et al., 1998). Also within country, when different national products within a specific region were compared, those better known locally showed the higher acceptability scores (Martinez, Sañudo, Panea, & Olleta, 2005). For consumers, the use of intensively reared systems with the inclusion of concentrates in the diets, even under grazing conditions, seems to be the best option to assure acceptability (Font i Furnols et al., 2009).

Regarding consumer's beliefs, the preferences are higher for lamb from grass-based production systems in comparison with lamb concentrate-fed (Font i Furnols et al., 2011). This is probably associated with consumer's beliefs and expectations, which ultimately are related to their considerations that grass production systems producer healthier, more natural and tastier lamb meat and they are also more friendly to the environment than more intensive grain feeding systems (Font i Furnols et al., 2011). These preferences were demonstrated towards beef raised on pasture (Verbeke, Pérez-Cueto, de Barcellos, Krystallis, & Grunert, 2010) and to pig organic production systems (Grunert, Bredahl, & BrunsØ, 2004). Moreover, consumers preferred lamb meat from mountain pastures than those from low-land pastures (Hersleth, Næs, RØdbotten, Lind, & Monteleone, 2012; Imami, Chan-Halbrendt, Zhang, & Zhllima, 2011). Lamb from mountain pastures was associated with production systems that produce better flavor, more natural and healthier lamb meats, and more care of the environmental and animal welfare issues, as well as to genetic specificity for plants and animals which may produce a promising sensory specificity (Hersleth et al., 2012). Additionally, it has also been proven that expectations of consumers towards lamb meats originated from different production systems are not necessarily confirmed when consumers tasted (experienced) the meat in blind conditions (Font i Furnols et al., 2011).

Thus, consumer's beliefs are very important and affect consumers purchasing intention. Even more, these beliefs regarding lamb meat are different depending on the segment of consumers considered, which determines these beliefs or purchasing intentions (Font i Furnols et al., 2011; Sepúlveda et al., 2011).

Labeling information about production systems (mainly animal feeding and environmental friendly production practices) are relevant for an important segment of consumers which are very concerned about safety of lamb meat, nutrition and health and sensory satisfaction obtained (Bernués, Olaizola, & Corcoran, 2003a,b). Nevertheless, consumers usually do not have information about these extrinsic cues and, consequently, they cannot use this information in their quality evaluation (Bernués et al., 2003b) to confirm or disconfirm their expectations. However, some works has proven that providing information to consumers about feeding or animal welfare practices in terms of rearing conditions previous to lamb consumption, influenced consumer acceptability, moving it towards to the satisfaction of their expectations (defined as "assimilation effect") (D'Alessandro, Maiorano, Kowaliszyn, Loiudice, & Martemucci, 2012; Napolitano et al., 2007; Piasentier, Morgante, Saccà, Valusso, & Parente, 2007). This effect is very important because it demonstrates the influence of information on consumers' acceptability of lamb, as well as the importance that consumers give to more sustainable and "naturally" produced lamb meat from grass-fed feeding regimes, that could be used in marketing strategies.

### 3.5. Consumer perceptions and animal welfare

Consumers increasingly criticize globalization of agricultural production and question economic, environmental and social consequences of global trade (Abbott, 2003; Jones, Comfort, & Hiller, 2003; Raynolds, 2000). Ethical consumerism is gaining relevance in food purchase decisions (Miele & Evans, 2010; Newholm & Shaw, 2007; Shaw & Shiu, 2001; Vermeir & Verbeke, 2006) and good examples of this trend in the food market are 'Fairtrade' and (partly) organic products, which have exhibited impressive growth rates during recent years (Zander, Stolz, & Hamm, 2013).

For the last 20 years, literature has being indicating that consumers are acquiring an increasing interest in farming practices and related animal welfare standards for defining animal-food purchases (McInerney, 2004; Verbeke & Viane, 1999). In 2001, Harper and Henson (2001) determined that consumers in Western countries are more influenced by the ethical aspects of food production than by their cost, and there is a growing interest in the animal welfare standards associated with production practices. In 2003, Blokhuis, Jones, Geers, Miele, & Veissier, 2003, reported that animal welfare is recognized as an important component of quality assurance for consumers of products of animal origin. However, the results of various investigations have been inconclusive regarding the importance of animal welfare when choosing meat. According to the Special Eurobarometer, European Commission (2005), almost half of all EU citizens think that the animal welfare and protection within the EU are better than in other parts of the world, but a slight majority of EU citizens (52%) seem not to take into account animal welfare issue when they buy food. In Scotland, Schröeder and McEachern (2004) also concluded

that consumers avoid buying meat products produced in intensive systems if animal handling affects meat quality, but they found a low proportion of consumers willing to pay more for such meat. McCarthy, De Boer, O'Reilly, and Cotter (2003) reported that animal welfare did not significantly affect the attitude toward beef and its consumption in Ireland. Some studies highlighted that animal welfare is relatively less important than other attributes, such as animal feeding, origin (Bernués et al., 2003a), food appearance and price (Davidson, Schröder, & Bower, 2003). Napolitano, Caporale, Carlucci, and Monteleone (2007b) concluded that if the meat is acceptable in terms of sensory properties, information about animal welfare and nutritional characteristics allow the consumers to gain a more positive perception of the product and increase meat acceptability in Italy. Recent studies in the EU indicated that consumers are willing to eat animal friendly food because they associate it with higher quality and health (Napolitano, Caporale, Carlucci, & Monteleone, 2007; Special Eurobarometer, European Commission, 2007).

Similarly, it has been reported that sensitivity with respect to animal welfare differ according to gender, education level, occupation (María, 2006), age (Bernués et al., 2003a; María, 2006), country of residence (Bernués et al., 2003a; María, 2006) and place of residence (Bernués et al., 2003a). Grunert and Valli (2001) identified one consumer segment, characterized by young people with high income and educational levels, for whom it is very important that animals receive appropriate treatment. In Spain, Sepúlveda et al. (2011) also reported that even when environmentally friendly production and production practices that respect animal welfare are among the aspects that are least valued at the time of purchase, there is a segment of young consumers for whom these aspects deserve a higher rating. There is also evidence to suggest that people who have already visited a farm which rears animals are most likely to consider the welfare of those animals that are the source of meat products (Special Eurobarometer, European Commission, 2005). Hence, studying consumption habits and attitudes towards certain meat attributes must take consumer segmentation into account. In that sense, it should also be very important to consider consumer segmentation and the significant differences within country or between countries, for developing marketing strategies (demand driven oriented) in Europe (Font i Furnols et al., 2011) and around the world, by producers and exporters of lamb meat.

The topic of animal welfare is also gaining importance in the Americas (Schnettler, Vidal, Silva, Vallejos, & Sepúlveda, 2009). The traditional livestock exporting countries (Argentina, Brazil, Canada, the United States, Paraguay and Uruguay) and those emerging (Chile and Mexico) have incorporated different aspects of animal welfare into their regulations and practices, mainly associated with beef exports (Rojas, Stuardo, & Benavides, 2004). However, Latin American consumers' attitude towards animal welfare is not well known yet (Schnettler et al., 2009).

Information cues on environmental factors, animal welfare and animal feeding are highly relevant for many consumers (Bernués et al., 2003b). Moreover, to previous studies about organic products, this kind of information may markedly increase consumer willingness to pay (Napolitano et al., 2010). Despite this increasing interest on information, ethical values are only rarely communicated to consumers (Zander & Hamm, 2010).

It was highlighted by research that carefully informed consumers have a favorable image about extensive livestock systems and associate them with positive attributes about lamb meat, while more intensive systems create negative expectations and may influence and penalize the qualitative assessment of the meat. They even change previous hedonic scores, and scores for tenderness, flavor or juiciness from previous blind test showing an assimilation effect (D'Alessandro et al., 2012). Therefore, information about animal welfare, expressed in terms of rearing conditions, can be a major determinant of animal-based food acceptability, thus providing a potential tool for meat differentiation in traditional farms where husbandry is based on extensive rearing systems and high animal welfare standards.

Independently from the animal species, fresh meat is usually commercialized as undifferentiated product (Napolitano, Caporale, Carlucci, & Monteleone, 2007), especially lamb (Grunert, 2006; Grunert & Valli, 2001). Sheep producers and the meat industry should take into consideration that the feeding system is considered by some consumers to be a key extrinsic quality attribute of meat (Bernués et al., 2003a; Sepúlveda et al., 2011) and that consumers mainly prefer feeding systems based on pasture and forages rather than cereal-based ones (Font i Furnols et al., 2011). This added to the exposed advantages for human health for consuming lamb meat produced on grass-fed animals (Cañeque et al., 2008) implies that lamb exporting countries with predominant pastoral production systems like in the case of Australia, NZ and Uruguay, the important effect of information about animal welfare associated with rearing conditions and product acceptability, may give some indications about the possible way to differentiate sheep meat products (McInerney, 2004). That information given to the consumers should be based on real scientific information covering production system aspects (del Campo, 2008, 2011; del Campo & Montossi, 2007) where consumer ethical concerns about animal welfare are addressed (Napolitano, Caporale, Carlucci, & Monteleone, 2007). The double challenge should be to generate objective information about their comparative advantages in relation to animal welfare, but not less important, to improve those practices associated to this systems that could compromise animal welfare (del Campo, 2012), even if those threats are not directly perceived by consumers.

### 3.6. Origin effect on lamb meat acceptability

Sheep production systems vary considerably across the world, and reflect the different local environmental conditions, which determine, to a large extent, breeds, housing, intensification level, management practices, environmental issues, and animal feeding systems used. The components of the production systems are considered to be most important ones in determining quality in animal production (Sepúlveda et al., 2011). For this reason, lamb meat has different sensory characteristics depending on its origin, being a product strongly country-dependent. Thus, lamb sensory evaluation by consumers from different origins can produce differences in their acceptability. However, a part of this sensory differences, there are other aspects inherent to consumers that affect their evaluations and preferences for meat depending on its origin. At the end of the supply chain, market requirements and qualities also play a relevant influence on the quality needed.

Origin is an important extrinsic cue that affects preferences of consumers in food purchase decision-making, being in general local or national products the most preferred by consumers, given that they are considered fresher, tastier and with higher quality (Chambers, Lobb, Butler, Harvey, & Trail, 2007). The effect of the origin includes aspects related with consumer's beliefs, feelings or emotions and moral considerations (Obermiller & Spangenberg, 1989) as well as interaction among them (Verlegh & Steenkamp, 1999). Moreover, in this sense, expectations created by consumers due to origin of lamb can influence their preference or acceptability, either positively or negatively (Pauselli, Morbidini, Lasagna, Landi, & Giangrande, 2009). However, this origin preference depends on various factors such as the type of product, the characteristics of the country of origin in terms of economic development, production characteristics, neighboring and culture similarities, and also, the socio-demographic characteristics of consumers (Alfnes, 2004; Cowan, 1998; Juric & Worsley, 1998; Kaynak, Kucukemiroglu, & Hyder, 2000; Schnettler, Ruiz, Sepúlveda, & Sepúlveda, 2008). Consumer ethnocentricity is a normative aspect related to country of origin and it happens when consumers think that purchasing imported products is wrong for the domestic economy, morality and patriotism (Shimp & Sharma, 1987) and, as a consequence, consumers overestimate local products, and they preferred them and are morally obliged to buy (Sharma, Shimp, & Shin, 1995).

Historically, it has been shown that in areas with low sheep meat consumption (e.g. Central and South Eastern Asia and the USA), sheep meat is generally disliked because of its strong flavor and odor. However, in areas where large populations of sheep meat are consumed (e.g. Middle East and New Zealand), consumers apparently enjoy its distinctive flavor (Jamora & Rhee, 1998; Rubino, Morand-Fehr, Renieri, Peraza, & Sarti, 1999). Also, different lamb studies show that national or even local/regional lamb is the most preferred one (Bernués et al., 2003a, 2003b; Hersleth et al., 2012; Pauselli et al., 2009), even for the segments of consumers that gave less importance to the origin of the meat (Font i Furnols et al., 2011) or independently of the consumers' frequency of lamb meat consumption (Bernabéu & Tendero, 2005).

Also, studies carried out with trained panelists or others with current lamb meat consumers (Griffin et al., 1992; Sañudo et al., 1998), investigated the dependency between culinary background and acceptability, and they found some clear relationships between knowledge of the product and its acceptability. Also, Font i Furnols et al. (2006) found that European consumers appreciated more the meat from local lamb than meat from lambs that had been reared on pastoral production systems from South America. On the other hand, Canadians (Jeremiah, 1988) did not detect major differences in flavor and texture of lambs from different origins like Australia, New Zealand and Canada, probably due to all those lambs had similar rearing systems and carcass weights. This tendency is also demonstrated even when meat is not tasted, thus, in a study carried out in 4 European countries (Spain, United Kingdom, Germany and France) comparing acceptability of different labels, Swiss lamb labeled was the second preferred after the local one, being lamb meat from Argentina or Uruguay the less preferred. The authors hypothesized that this preference was due to the fact that Switzerland has a similar level of development and social systems to rest of the European countries involved in the study, and also given by its proximity of those countries, where meat could be perceived as fresher and healthier (Font i Furnols et al., 2011). This result indicates the importance of the characteristics of the country of origin of the lamb meat in the preferences of consumers. In another work performed in England, France, Italy, Scotland and Spain, the origin of the meat was also important in all the countries. When segments of consumers were established, those segments more concerned about origin of the meat were mainly composed by consumers from medium-size and big cities (Bernués et al., 2003b), indicating the influence of socio-demographic characteristics of the consumers in their preferences.

In some others research studies, the origin of meat has been associated with meat safety and healthy, especially in beef but also happened in chicken and pork (Cowan, 1998). This relation has also been pointed out in lamb by Italian consumers (Hersleth et al., 2012), although it was not confirmed in a Spanish study (Bernués et al., 2003a).

Information about extrinsic cues like origin and production systems is not usually available for consumers. One of the ways to provide this information is the use of a brand or a designation of origin scheme, given that branding is a tool to collaborate with consumers to associate the product with different attributes of the production process (Acebrón & Dopico, 2000; Bernués et al., 2003a). Lamb labels, including organic ones (Angood et al., 2008), can create positive consumer expectations. It is also important that consumers can confirm them by a favorable sensory experience of the evaluation of meat, to avoid further disconfirmation and risking failure (Piasentier et al., 2007). In this sense, traceability and certification are important (Du Plessis & du Rand, 2012) tools to ensure this process. In Europe, there are different geographical indications and traditional specialities to guarantee the origin of some products in terms of production, processing and/or preparation. This should be a way to follow in the future.

## 4. Implications

Sheep industries around the world are very dissimilar given the huge variation presented in natural resources, social, economical, cultural, technological, and geo-political issues among others. Therefore, the authors are very conscious that many of the technological proposals, productive advantages and disadvantages, social–economical opportunities and limitations, and market accesses and constraints addressed here to improve sheep industry competiveness, could work properly for some production systems and markets, or produce neutral to even negative impacts in other situations. It is also important to highlight the decisive influence of culture, beliefs, values and education elements from sheep industry shareholders and consumers worldwide, which definitively shape the final impact of those along the sheep meat chain.

This work has been focused on the evaluations of the interrelationships between factors associated with inside farm issues and consumer preferences. We do recognize the relevant effects of other factors, like animal transportation, meat processing and packaging, meat cooking, meat marketing and media position, which will have an influential response particularly on consumer preference, but they are out of the scope of this article.

Based on the ample information presented in this article, the authors concluded that undoubtedly "we" (sheep industries and societies worldwide) do not have a single answer to propose strategies and solution to solve many of the contradictions and conflicts generated between the intensification of productions systems, sustainability (economical, social and environmental) issues, and consumer preferences, beliefs, and values. Furthermore, extensive production systems also have actual and potential limitations to response positively to some of the challenges imposed by the observed consumer's perception trends.

In many cases, the intensification and automatization of sheep production systems appears to be a positive response to increase productivity and profitability and even to promote the reduction of GHG emissions. However, not all the farmers will benefit at the same extent, given the capital and final investment, education, organizational support and personal and family motivation needed to follow this approach, particularly in small-scale operations. Sheep farmer numbers are very important, thus, government regulations must take them into account from economical, social and environmental point of views, in order to maintain them and their families on the land, particularly on extensive, marginal, and remote areas. Furthermore, there is clear scientific evidence from consumer perception studies, particularly those performed in important markets (e.g. EU) dominated by consumer with western lifestyle and medium to high incomes, which demonstrated a negative opinion about intensification, moving away from extensive and "natural" ways of production. In addition, lamb meat produced on grass-based systems is healthier for humans than that produced on concentrate-based systems. For human health purpose, we recognize that the concentration of recommended fatty acids (e.g. of LC n−3 PUFA) in lamb meat raised on grass is substantially lower than that on fish and seafood. Anyway, this fact has to be combined to obtain synergic advantages: a) contributes to a balanced and healthier diet and b) is perceived by consumer as meat produced under friendly environmental manner. This is a key opportunity to use these production systems to develop marketing strategies.

These studies demonstrated that consumer perceptions, beliefs, and values are very important on determining their acceptability of meat. Most of the consumers prefer meat coming from more "sustainable" production. Nevertheless, after tasting, meat preferences very often change substantially, unless information is provided, indicating the importance of consumer's expectations, which are influenced by beliefs, feelings and emotions. Within some segment of consumers, the price of meat also affects consumer's purchasing decisions.

There are no doubts about the current importance of genetic improvement in sheep industry competitiveness and particularly in its future. There are good examples of interesting genetic gains for different traits in sheep meat (mostly on growth and carcass quality, and less in meat quality) achieved by the use of different genetic tools.

Worldwide, the use of genomic selection is the more recent application in the sheep industry in comparison to other animal industries. There are few technology products generated by genomic selection available for producers, but there is no one for carcass and meat quality traits. However, the future potential of this technology is enormous, and opens a new era for animal genetic improvement. Furthermore, the next step is the application of genetic engineering in animal selection, which could revolutionize animal production in the world, particularly when water and land resources are scarcer (used for other very profitable alternatives like cropping) or marginal for livestock production. However, in the near future, the probability to have GM commercial products in the market available to sheep farmers is low, and also it will face a clear negative perception from consumers.

Consumers, mainly on industrialized countries, (led by EU) are paying more attention on the animal quality of life on the farms. This trend is accompanied by ethical claims and the pressure made from animal welfare groups as well as by the official regulations or private entities, demanding the implementation of best management practices to promote animal welfare on farming systems. A sustainable production system includes holistically the animal welfare component, where farmers are responsible for the well-being of animals in front of the society. This is certainly an international trade issue, which is also gaining followers at household level in many countries in the world. This article has addressed several advantages and disadvantage of extensive and intensive sheep production systems, where there is a clear ground for improvements. It also highlighted that the application of animal welfare practices for intensive productions systems cannot be directly applied for extensive production systems. The best management codes of practices have to contemplate these important differences. The advance of science, the education and training of people along the sheep industry are strategic keys to improve animal welfare. This has to be accompanied by proper and effective ways of communications with the rest of the society. Finally, the worldwide improvement of animal welfare will become a reality, if it is designed with a holistic approach (ethics, culture, environment, society and economy) and it is sustained by the support and progress of science, respecting the diversity and reality differences between developed and undeveloped countries, and based on the cooperation and understanding of the sheep industry and the societies of the world.

Meat consumption is associated with certain risks to human health and safety scares. To reduce this awareness should be developed in information systems which include specially origin and handling of meat products, among many other issues, in order to guarantee safety. HACCP provides the basis for the food safety management system, together with information of traceability along the supply chain. In some cases, food safety can determine consumer's purchasing decisions.

It cannot be omitted that Halal lamb meat market represents a great potential in lamb productions and consequently, it would be worthwhile to study the production of lamb in a sustainable way that can be used also for this type of market.

At world level, the public and private investments in research and innovation on pig, poultry and beef meats are substantially higher than that on sheep meat, and we do not see any substantial change on this tendency for the near future. This reflects the size and type of business between the different meats. In the long term, this reality could probably affect negatively the rate of gain in productivity and efficiency progress of sheep enterprises in comparison with the other alternative meats. Taking this possible scenario into account, the way to keep or even increase sheep meat participation in the overall meat consumption will probably rely on the differentiation and adding value, and offering a unique, healthy, tasty, safe and distinguish product, particularly to those consumers which desire and that are able to pay for such differentiate meat.

It also has been demonstrated that sustainable production can be done at different levels with more or less effects on meat quality, production costs, animal welfare or environment, among others. Thus, it is important to find a balance between sustainability at the production level, quality of the meat produced and the information provided to consumers.

We support the strategy of aligning production systems, practices, and technology to target the preferences of different segments of consumers and gain their loyalty in different niches of the sheep meat market. This approach has to be accompanied by the necessary verifications of accomplishments of production and processing procedures and product quality and safety, including labeling. Among others, labels should include the identification of country of origin and nutritive value of the meat. This is not new in the sheep meat market, but probably, in the medium-long term this approach could probably be generalized. In this scenario, the inclusion of full traceability systems "from the animal to the plate" could be a stronger platform to make more competitive sheep meat compared with other meat alternatives.

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