Implications of Genotype by Environment Interactions in Dairy Sheep Welfare

Dinu Gavojdian*, Szilvia Kusza, András Jávor

Faculty of Agricultural, Food Sciences and Environmental Management, University of Debrecen
4032, Böszörményi str 138, Debrecen, Hungary

Abstract
Small ruminants are the most extensively farmed livestock species in Europe, as a result being extremely exposed to natural hazards which leads to strong interactions between genotype and environment. Aim of the current review was to outline and discuss the main welfare issues and economic implications with regards to the genotype by environment interactions in dairy sheep. Researches concerning the additive genetic effect on milk yield, shown that this accounts only for 10%, while the milk production is 90% influenced by environmental factors, highlighting the major role that management and nutrition play in the dairy production of sheep. Nowadays, dairy sheep breeds (e.g. Eastern Friesian and Lacaune), are being introduced and reared in various countries under an extremely wide range of rearing conditions, without adequate knowledge on their acclimatization to the new specific conditions. It was concluded that a welfare assessment protocol for dairy sheep does not exist up today, moreover, there is a serious lack of data concerning the genetic and environmental factors affecting the welfare status of dairy sheep at farm level under different production systems.

Keywords: animal welfare, genotype by environment interactions, lactating sheep, lameness, mastitis.

1. Introduction

Small ruminants are the most extensively farmed livestock species in Europe, as a result being extremely exposed to natural hazards which leads to strong interactions between genotype and environment (G x E). In Eastern and Southern Europe, *low input* production systems are practiced, with indigenous Zackel and Tsigai groups being predominant, in some countries Merino strains being of importance (e.g. Hungary).
Previous studies shown the major role that G-by-E interactions have on production levels, genetic improvement, reproductive performance and functional traits in ruminants, with a potential negative impact on the overall profitability of the industry and animal welfare.

* Corresponding author: Gavojdian Dinu, (+40)723375804, gavojdian_dinu@animalsci-tm.ro

Currently, in Europe exotic specialized sheep breeds are being introduced into various rearing systems and countries without adequate knowledge on breed acclimatization to the new specific conditions.
Aim of the current review was to outline and discuss the main welfare issues and economic implications with regards to the genotype by environment interactions in lactating sheep.

2. General overview of the EU dairy sheep industry

Livestock farming in the European Union represents an annual value of 149 billion euros and the number of people handling animals in the context of an economic activity can be estimated at around 4 million, while the farming sector uses around 2 billion birds and 334 million mammals per year [1].
In Europe, sheep production systems vary greatly among countries and regions. In most regions of

the Mediterranean countries, the production of dairy sheep is predominant [2, 3], while in North, Central and Eastern Europe, meat has become the main product of sheep [4, 5].

Currently, in EU region are being reared 68.905.200 sheep, for both meat and milk production, with wool production as a marginal product [6].

Generally, sheep are being regarded as heaving high tolerance to environmental and production factors. As a consequence, few studies have been carried out to assess the implications that genotype by environment interactions have on the overall productivity and welfare in sheep, and particularly in vulnerable categories such as lactating ewes and newborn lambs [7-9].

Ewe milk production varies greatly between sheep breeds, mainly because of the different feeding management of flocks and of the genetic improvement schemes practiced. Some breeds, due to selection and proper nutrition, may be able to produce yields higher than 600 kg of milk/lactation, taking into account the heritability for milk yield, that ranges between 0.20-0.29 [10-12], with individuals that produced under experimental conditions over 1.400 kg of milk/lactation.

Researches concerning the additive genetic effect on milk yield, shown that this accounts only for 10%, while the milk production was 90% influenced by environmental factors, highlighting the major role that management plays in the dairy production [13].

3. Importance of genotype by environment interactions

Genotype × environment interaction is a term used to describe the phenomenon that occurs when a set of genotypes change their relative performance in different environments. G x E can form a potential source of inefficiency in animal breeding if selection decisions are made without acknowledging their effects [14].

Recent developments in the use of random regression models have led to the suggestion that the G x E effects can be empirical investigated by regressing breeding values on some measure of the environments [15]. Previous studies have shown that selection of the best performing animals under good management conditions increases environmental sensitivity [16, 17], which leads to poor performances, when environment conditions are unfavorable. Especially poor performances in terms of health and welfare traits (e.g. lameness, infertility, mortality rates), which is not acceptable due to the negative economic effects, and also because of the ethical implications [18].

Functional traits in sheep are considered to be the following: stillbirth rate, losses until first mating, litter size, lambing interval, and longevity [19].

According to the Strategic Research Agenda of the Sustainable Farm Animal Breeding & Reproduction Technology Platform (FABRE), set up by the EU Commission, genotype x environment interactions, including production and functional traits in sheep should represent a long-term-high priority research topic.

Due to globalization of livestock breeding and differentiation of farming systems, G x E is getting more and more important in breeding programs [18]. Nowadays, similar to the pattern found in dairy cattle, few specialized sheep breeds (e.g. Lacaune, Eastern Friesian), following exports, are being reared in various countries under an extremely wide range of rearing conditions.

As a result, newly introduced specialized breeds can under-performed the native breeds, or production costs can be negatively affected by the rise with the veterinarian treatment, feed and housing costs. G x E effects may be used to describe how environmental characteristics such as climate and topography affect the production of different genotypes, and for clustering of environments, thus facilitating improvement of breeding programs and management schemes for domestic ungulate populations [20]. Phenotypic plasticity being the property of a genotype to develop systematically different phenotypes in different environments [21]. Inter-breed differences by means of plasticity are being mentioned frequently in previous studies done on ruminants.

4. Importance given to Animal Welfare in EU

Article 13 of the Treaty on the Functioning of the European Union recognizes animals as sentient beings and requires full regard be given to the welfare requirements of animals while formulating and enforcing some EU policies.

Animal welfare is the subject of rapidly increasing concern in most developed countries in the world and this concern is resulting in changes in the ways in which farmers and other stakeholders manage and rear animals.

Starting the year 2000, the European Union has dedicated on average nearly 70 million euros per year to support animal welfare, out of which 71% is directed to farmers as animal welfare payments from the European Agriculture Fund for Rural Development, while the rest is dedicated to all other EU activities relevant to policy making: research (21%), economic studies, education, training, enforcement, etc [1].

Animal welfare is the combination of subjective and objective (qualitative and quantitative) aspects of the conditions of life for animals, including health and disease, behaviour, husbandry and management, and is thus, a complex and abstract construct [22]. Moreover, since the animal welfare can be considered to be the outcome of the interaction between genotype, management and the environment [23], a valid assessment of welfare should include animal-based welfare outcomes [24].

Valid welfare indicators being required by farmers, veterinarians, the sheep industry and farm inspectors in order to measure and monitor on-farm welfare standards for certification, farm assurance and legal purposes [25].

In practice, animal welfare is usually measured using different indicators, these are mainly body damage, disease, growth rates, reproductive performance, stress and behavioral abnormalities (e.g. stereotypes and aggressiveness). Animal observation can provide information on body condition, performance and behaviour [26], while stress is usually assessed by the level of plasma cortisol, which reflects the activity of the hypothalamus–pituitary–adrenal (HPA) axis.

During the last decade, the scientific assessment of animal welfare has developed substantially and many studies on different species have been carried out. Information from such studies is used by legislators, food companies and the public with the consequence that the various kinds of regulation lead to real improvements in animal welfare [27].

Animal-based indicators are those that are based on the inspection of the animals or the study of farm records, while resource-based (environment-based) indicators are based on the characteristics of the housing and management system [28].

According to the EU Strategy for the Protection of Welfare of Animals 2012-2015, the possibility of using scientifically validated outcome-based indicators complementing prescriptive requirements in EU legislation will be considered with a specific attention to the contribution of such new approach to the simplification of the acquis.

Animal-based indicators have been introduced in two recent pieces of EU animal welfare legislation (Directive 2007/43/EC laying down minimum rules for the protection of chickens kept for meat production and Regulation (EC) No 1099/2009 on the protection of animals at the time of killing). The use of outcome-based animal welfare indicators is also recognized at international level by organisations such as the World Organisation for Animal Health (OIE) [29].

5. Concerns in sheep welfare

Dairy sheep can be reared under a diversity of conditions, even within the same farm: from free range grazing exposed to natural hazards and surveillance depending exclusively on the availability of pasture resources, to full time indoors management. In consequence, the number and quality of human-sheep interactions can be equally very diverse, as well as the potential impact of farming practices on animal welfare resulting for example in poor body condition, high levels of mortality, abortion, lameness, or mastitis. Up today the welfare of sheep is commonly envisaged by the general public as providing better standards compared to dairy cattle or the poultry and pig sectors [30].

Some of the existing definitions of sheep welfare are rather descriptive or refer to an animal being ‘in harmony’ with its environment. However these definitions are not helpful for the scientific assessment of sheep welfare at farm level.

Researches on assessment of distress in sheep have used one of the three following approaches: measures of general body functioning (e.g. milk yield, weight gain, SCC); measures of physiological responses (e.g. plasma cortisol or ACTH concentrations) and measures of behavioural changes (e.g. vocalization or locomotion). All three approaches have merit and can be useful within different contexts [31].

Lactation period imposes great stress on the ewe's organism due to changes that occur in the animal's organism during a short time period: parturition; debut of lactation; involution of the genital tract; mobilization of the body reserves (the ewe can lose 80% of the fat reserves); reduction of the body condition; separation and weaning of the lamb(s) (especially in dairy ewes, where the weaning takes place at a very early age for maximizing milk yield), manual or mechanical milking etc. Therefore, lactating ewes can be considered a vulnerable category, and additional stressors should be kept to a minimal throughout proper management in order for the animal to better cope with the physiological-changes and the performance of the animals to not be negatively affected during this period.

Due to the fact that sheep are a highly gregarious species, being isolated is one of the most stress-inducing events [32]. Psychological distress in post-parturient ewes is provoked by separation from the lamb, in particular in the postparturient period. While diseases can also provoke a systemic reaction that activates the stress axis [33] and disrupts the display of normal behaviours.

Reducing space allowance, overcrowding, frequent regrouping can lead to increase in aggressive interactions and is considered to be highly important for optimum welfare and production.

Additionally, body condition which is the outcome of on-farm husbandry and management can therefore be a key tool in the on-farm assessment and management of sheep welfare [34].

In sheep, plasma cortisol levels increases when they are exposed to adverse conditions [35], thus the cortisol response could prove as an indicator of stress and be used in welfare studies.

For this reason, it might be concluded that a welfare assessment protocol for dairy sheep does not exist up today, moreover, there is a serious lack of data concerning the genetic and environmental factors affecting the welfare status of dairy sheep at farm level in different production systems.

In a study conducted on lactating Merino ewes kept on pastures for 9 hours/day vs. ewes kept indoor-housed, [36] found that the grazing system had a positive effect on *in vivo* cellular immune response, while grazing animals produced more milk than the penned ones with increased content of milk fat ($p < 0.05$).

Previous studies shown that throughout the exposure of lactating ewes to solar radiation under high ambient temperature, milk yield was reduced with up to 20% in respect to the control groups who were provided with shade [37]. As a result, simple exposure to solar radiation could influence the ranking of animals from one genotype when performance testing and EBV's are being performed.

Researches focusing on g x e interactions in sheep, have shown that different genotypes reared under identical conditions perform differently by means of organic resistance.

In a study following the influence of the ram's genotype on survival rates in unweaned lambs, results have shown significant difference by terms of survival in East Friesian and Suffolk sired lambs, and found significant differences between the two genotypes with averages of 82.1% and 97.1%, respectively [38].

Similar results of genotype influencing significantly ($p \leq 0.01$) the organic resistance in sheep were reported in fattening lambs reared extensively on pastures in Romania, in a comparative study following lameness incidence between indigenous Turcana and the South African native Dorper breeds, with an incidence of 17.0% and 32.3%, respectively [39].

6. Tackling the dairy sheep welfare

Most prominent welfare issues in dairy ewes are considered to be: mastitis, lameness, internal parasitism, mortality and dystocia.

By far, in means of incidence and economic importance, mastitis represents the most important of all technopaties. In dairy sheep commercial flocks sub-clinical mastitis incidence is of 16-35% [40] with clinical mastitis most commonly affecting 3-5% of the lactating ewes. If treated, ewes with sub-clinical mastitis produce less milk with 15-20%, and in the case of an re-infection, the milk yield might drop with 30% [41]. In Greek Chios breed, mastitis was the cause for culling 46% of the multiparous ewes [42]. Heritability for both mastitis resistance and SCC are considered to be low, with average values reported ranging between 0.11 and 0.14 [43, 44].

Currently there is growing interest in finding candidate genes to be used in genomic selection for the genetic resistance to mastitis, especially in the French Lacaune breed. QTL's could prove suitable to be used, in association with phenotypic data, given the importance of mastitis in all dairy species. An estimation of the costs to the EU per year due to mastitis in sheep was of 37 million Euros [45].

The prevalence of lameness in commercial farms registers values ranging from 5 to 36%, with infectious lameness being able to affect over 50% of the flock. From the animal welfare point of view, the acceptable incidence for lameness in sheep flocks is 5%, with the best managed flocks registering values lower that 2%.

In a comparative study between Blackface breed and the English Mule [46], during two consecutive years, foot rot incidence ranged between 17-18% in Blackface sheep and between 43-56 in Mules. With heritability estimates of 0.23 and 0.14 in Mules and Blackface, respectively.

Parasitic infestation is one of the most challenging aspects in sheep management. Clinical and sub-clinical infestations can result in severe loss of body weight, reduced milk and wool, and even death, in both lambs and adult sheep. There are concerns about the growing anti-helmintic resistance in sheep, with treatments giving less results.

Studies concerning genetic parameters for fecal egg count in Merino breed found a moderate heritability of this trait of 0.24, suggesting that this trait could be included in a selection index [47].

There have been studies to outline that genotypes perform different by means of parasitic resistance in same environments, for instance Red Masai sheep shown to have higher genetic resistance to internal parasitism, compared to Dorper breed [48]. Furthermore, a recent study which identified single nucleotide polymorphisms (SNPs) within candidate genes located in sheep chromosome 3 (Oar3) as well as genes involved in major immune pathways demonstrated strong phylogeographic structure and balancing selection operating at SNP loci located within immune pathway genes in 22 sheep breeds from Asia, Europe and South America [49].

Mortality causes in adult ewes is considered to be a complex of nutrition (e.g. starvation), management, environment (e.g. heat stress) and disease factors. Estimated pre-weaning mortality ranges between 10 and 30% [50]. Previous studies shown that under identical management conditions, the genotype can significantly influence the survival rates of sheep. For instance, in a comparative study following survival from, it was shown that under the same rearing conditions, East Friesian, Lacaune and Suffolk lambs register survival rates of 82.1%, 95.5% and 97.0%, respectively [51]. Mortality rates in adult dairy ewes ranges usually between 3-5%, with reports following the introduction of exotic breeds to contrastant environments which give data as high as 30-35%. Heritability for life span in Merino breed tends to increase with age of the groups of animals taken into study, with values being reported of 0.07, 0.10 & 0.13 at 3, 4 & 5 years of age, respectively [52]. Which takes us to the hypothesis that survival rates should be primarily improved by means of management, rather then selection, due to the low heritability of this trait.

7. Conclusions

Dairy sheep welfare receives less concern from the general public, decision makers and researchers compared to other dairy species (e.g. cattle or goats), and that reflects in the little data available regarding the subject.

Moreover, there is a need for developing a welfare assessment protocol for the sheep dairy sector, which to be used as a reliable and feasible tool in evaluating lactating sheep well-being.

Using both phenotipyc data from farms and the genomic selection tools available, some of the current dairy sheep welfare issues could be improved.

Genotype by environment interactions have been shown to severely affect both sheep welfare and economic performance of the flocks. As a result, efforts should be made to better understand performance and adaptability of dairy sheep, especially when new genotypes are being introduced into contrastant environments.

Acknowledgements

This research was realized in the frames of „National Excellence Program - working out and operating an inland student and researcher support, identification number TÁMOP 4.2.4.A/2-11-1-2012-0001”. The project is realized with the help of European Union and Hungary subsidy and co-financing by the European Social Fund.

References

1. Communication from the Commission to the European Parliament, the Council and the European economic and social Committee on the European Union Strategy for the Protection and Welfare of Animals 2012-2015, http://ec.europa.eu /food/ animal/ welfare/actionplan/docs/aw_strategy_19012012_en.pdf
2. Sorensen, J.T., Edwards, S., Noordhuizen, J., Gunnarsson S., Animal production system in the industrialized world, Rev. Sci. Tech. Off. Int. Epis., 2006, 25(2), 493-503
3. Papageorgiou, F., Culture and nature: The European Heritage of Sheep Farming and Pastoral Life, Research Report for Greece, Research Theme 2: Architecture, 2011,, http://prismanet.gr/canepal/en-publications/en-research-reports
4. Dyrmundsson, O.R., Sustainability of sheep and goats production in North European countries – from the Arctic to the Alps. 55th Annual Meeting of European Association for Animal Production, Bled, 2004, 5-9 September, Slovenia
5. Padeanu I., Meat production in sheep, Mirton Publ., Timisoara, 2010
6. EUROSTAT reports for 2011, http:// appsso. eurostat. ec.europa.eu/ nui/ submit View Table Action .do?dvsc=7
7. Dwyer, C., The Welfare of Sheep, Springer, UK, 2008
8. Caroprese, M., Casamassima, D., Rassu, S.P.G., Napolitano, F., Sevi, A., Monitoring the on-farm welfare of sheep and goats, Ital. J. Anim. Sci., 2009, 8 (1), 343-354
9. Sevi, A., Casamassima D., Pulina G., Pazzona A., Factors of welfare reduction in dairy sheep and goats, Ital. J. Anim. Sci., 2009, 8 (1), 81-101
10. El-Saied, U.M., Carriedo, J.A., Baro, J.A., De Le Fuente, L.F., San Primitivo, F., Genetic correlations and heritabilities for milk yield and lactation length of dairy sheep, Small Rumin. Res., 1998, 27 (3), 217-221
11. Legarra, A., Ugarte, E., Genetic parameters of milk traits in Latxa dairy sheep, Anim. Sci., 2001, 73, 407-412
12. Ligda, C, Gabriilidis, G, Papadopoulos, T, Georgoudis, A. Investigation of direct and maternal genetic effects on birth and weaning weight of Chios lambs. Livest Prod Sci., 2000, 67, 75-80
13. Oracova, M., Margetin, M., Peskovicova, D., Dano, J., Milerski, M., Hetenyi, L., Polak, P., Factors affecting milk yield and ewe's lactation curves estimated with test-day models, Czech J. Anim. Sci., 2006, 51(11), 483-490
14. McLaren, A., Lambe, N.R., Brothersone, S., Conington, J., Mrode, R., Bunger, L., Investigation into the presence of genotype by environment interactions in Scottish Blackface lamb traits, Small Ruminant Research, 2011, 105 (1), 46-52
15. Kolmodin, R., Strandberg, E., Madsen, P., Jensen, J., Jorjani, H., Genotype by environment interaction in Nordic dairy cattle studied using reaction norms, Acta Agric. Scand. Sect. A, 2002, 52, 11–24
16. Kolomodin, R.E., Strandberg, H., Jorjani, H., Dannell, B., Selection in the presence of a genotype by environment interaction: response in environmental sensitivity. Anim. Sci., 2003, 76, 375-385
17. Van der Waaij, E.H., A resource allocation model describing consequences of artificial selection under metabolic stress, J. Anim. Sci., 2004, 82, 973-981
18. Waltl, B.F., Baumung, R., Economic values for performance and functional traits in dairy sheep, Ital. J. Anim. Sci., 2009, 8, 341-357
19. Mulder, H.A., Methods to optimize livestock breeding programs with genotype by environment interaction and genetic heterogeneity of environmental variance, PhD. Thesis, 2007,Wageningen University
20. Steinheim, G., Odegard, J., Adnoy, T., Klemetsdal, G., Genotype by environment interaction for lamb weaning weight in two Norwegian sheep breeds, J. Anim. Sci., 2008, 86, 33-39
21. de Jong, G., Bijma, P., Selection and phenotypic plasticity in evolutionary biology and animal breeding, Livest. Prod. Sci., 2002, 78, 195–214
22. Fitzpatrick, J., Scott, M., Nolanm, A., Assessment of pain and welfare in sheep, Small Rumin. Res., 2006, 62, 55–61
23. Sorensen, J.T., Fraser, D., On-farm welfare assessment for regulatory purposes: issues and possible solutions. Livest. Sci., 2010, 131, 1–7
24. Mullan, S., Edwards, S.A., Butterworth, A., Whay, H.R., Main, D.C.J., Interdependence of welfare outcome measures and potential confounding factors on finishing pig farms. Applied Animal Behaviour Science, 2009, 121, 25–31
25. Phythian, C.J., Michalopoulou, E., Jones, P.H., Winter, A.C., Clarkson, M.J., Stubbings, L.A., Grove-White, D., Cripps, P.J., Duncan, J.S., Validating indicators of sheep welfare through a consensus of expert opinion, Animal, 2011, 5:6, 943–952
26. Pol, F., Courboulay, V., Cotte, J.P., Martrenchar, A., Hay, M., Mormede, P., Urinary cortisol as an additional tool to assess the welfare of pregnant sows kept in two types of housing, Vet. Res., 2002, 33, 13–22
27. Broom, D.M., Welfare in relation to feelings, stress and health, REDVET Rev. electrón. vet., 2007, http://www.veterinaria.org/revistas/redvet
28. Mantenca, X., What are appropriate animal - or resource-based methods to assess animal welfare? – Relevance for extensive systems, Welfare goals from the perspective of extensively managed sheep, Proceedings of a workshop held in Aberdeen, Scotlandon, 2007, pp. 53-55

29. Guiding principles on animal welfare of the International Animal Health Terrestrial Code, www.oie.int
30. Sossidou, E.N., Szucs, E., Cziszter, L.T., “Farm Animal Welfare and Society”, In: Book of Proceedings, ANIMBIOGEN in EU International Conference on “Welfare in Farm Animals”, Institute of Genetics and Animal Breeding of the Polish Academy of Science, Jastrzębiec, Poland, 2011, pp. 93-103
31. Weary, D.M., Niel, L., Flower, F.C., Fraser, D., Identifying and preventing pain in animals, Appl. Anim. Behav. Sci., 2006, 100, 64–76
32. Boissy, A., Bouix, J., Orgeur, P., Poindron, P., Bibe, B., Le Neindre, P., Genetic analysis of emotional reactivity in sheep: effects of the genotypes of the lambs and of their dams, Genet. Sel. Evol., 2005, 37, 381-401
33. Elenkov, I.J., Chrousos, G.P., Stress hormones, proinflammatory, and anti-inflammatory cytokines and autoimmunity, Ann. NY. Acad. Sci., 2002, 96, 290-303
34. Morgan-Davies, C., Waterhouse, A., Pollock, M.L., Milner, J.M., Body condition score as an indicator of ewe survival under extensive conditions, Anim. Welf., 2008, 17, 71–77
35. Mellor, D.J., Stafford, K.J., Todd, K.S., Lowe, TE, Gregory, N.G, Bruce, R.A., Ward, R.N., A comparison of catecholamine and cortisol responses of young lambs and calves to painful husbandry procedures, Australian Veterinary Journal, 2002, 80, 228-233
36. Brachieri, A., Pacelli, C., Verdone, M., Girolami, A., Napolitano, F., Effect of grazing and homeopathy on milk production and immunity of Merino derived ewes, Small Rumin. Res., 2007,69 (1-3), 95-102
37. Sevi, A., Annichiarico, G., Albenzio, M., Taibi, L., Muscio, A., Dell’Aquila, S., Effects of solar radiation and feeding time on behavior, immune response and production of lactating ewes under high ambient temperature, J. Dairy. Sci., 2001, 84, 629-640
38. Thomas, D.L., Berger, Y.M., McKusick, B.C., Preliminary results: Survival of high-percentage East Friesian lambs, Spooner Agricultural Research Station, University of Wisconsin-Madison Proc., 2012, pp. 1-3
39. Gavojdian, D., Sossidou, E., Pacala N., Ilie D., Effects of Genotype-by-Environment Interactions on Lameness and Pneumonia Incidence in Dorper, Turcana and F1 Cross-breeds Lambs during Heat Stress Exposure, in Præbel, A. and Kristensen T. N., Proceedings of the AnGR-NordicNET Workshop, Genotype-by-Environment Interactions and Adaptation of Farm Animals on Phenotypic and Molecular Levels, 2012, Tuusula, Finland
40. Arranz, J.J., Beatriz Gutierrez-Gil B., Detection of QTL Underlying Milk Traits in Sheep: An Update, in: Advanced Genetic Traits, Cellular Mechanism, Animal Management and Health, 2012, doi.org/10.5772/50762
41. Petrovic, M.P., Mekic, C., Ruzic, D., Zujovic, M., Genetic principles relating the improvement of milk yield in sheep and goats, Biotechnology in Animal Husbandry, 2005, 21(5-6), 73-78
42. Ligda, C., Papadopoulos, T., Mavrogenis, A., Georgoudis, A., Genetic parameters for tes t day milk traits and s omatic cell counts in Chiosdairy sheep, in Gabina D., Sanna S. . Breeding programmes for improving the quality and safety of products. New traits, tools, rules and organization? Zaragoza: CIHEAM Options Méditerraneennes: Serie A. Seminaires Mediterraneens, 2003, pp. 55- 59
43. Barillet, F, Rupp, R, Mignon-Grasteau, S, Astruc, JM, Jacquin, M., Genetic analysis for mastitis resistance and milk somatic cell score in French Lacaune dairy sheep, Genet Sel Evol., 2001, 33(4), 397-415
44. Rupp, R, Bergonier, D, Dion, S, Hygonenq, MC, Aurel, MR, Robert-Granie, C, Foucras, G., Response to somatic cell count-based selection for mastitis resistance in a divergent selection experiment in sheep, J Dairy Sci., 2009, 92(3), 1203-1219
45. Sustainable Solutions for Small Ruminants FP7 project, 2013, http://www.3srbreeding.eu/Publications
46. Conington, J., Nieuwhof, G.J., Hosie, B.D., Bishop, S.C., Bunger, L., Breeding For Resistance To Footrot In Sheep, http://www.eaap.org/ Previous_Annual_Meetings.pdf
47. Nieuwhof, G.J., Bishop, S.C., Costs of the major endemic diseases of sheep in Great Britain and the potential benefits of reduction in disease impact, Anim. Sci., 2005, 81, 23–29
48. Baker, R.L., Mugambi, J. M., Audho, J.O., Carles, A.B., Thorpe, W., Comparison of Red Maasai and Dorper sheep for resistance to gastro-intestinal nematode parasites, productivity and efficiency in a humid and a semi-arid environment in Kenya, Proceedings of the 7th World Congress on Genetics Applied to Livestock Production, Montpellier, France, 2002, pp. 1-4;
49. Pichler, R., Poli, M., Cristel, S., Cetra, B., Medus, D., Basar, M., Thiruvenkadan, A.K., Ramasamy, S., Ellahi, M.B., Mohammed, F., Teneva, A., Shamsuddin, M., Podesta, M.G., Diallo, A., Candidate Gene Approach for Parasite Resistance in Sheep – Variation in Immune Pathway Genes and Association with Fecal Egg Count, PLOS One, 2012, 9 (2), 1-16
50. Dwyer, C.M., Genetic and physiological determinants of maternal behaviour and lamb survival: Implications for low-input sheep management, J. Anim. Sci, 2008, 86, 246-258
51. Thomson, B.C., Muir, P.D., Smith, N.B., Litter size, lamb survival, birth and twelve week weight in lambs born to cross-bred ewes, Proceedings of the New Zealand Grassland Association, 2004, 66, 233–237
52. Hatcher, S., Atkins, K.D., Thornberry, K.J., Survival of adult sheep is driven by longevity genes, Proc. Assoc. Advmt. Anim. Breed. Genet. 2009, 18, 580-583