Clinical characteristics of lameness and potential risk factors in intensive and semi-intensive dairy sheep flocks in Greece

A. I. GELASAKIS (Α.Ι. ΓΕΛΑΣΑΚΗΣ), G. OIKONOMOU (Γ. ΟΙΚΟΝΟΜΟΥ), R. C. BICALHO, G. E. VALERGAKIS (Γ.Ε. ΒΑΛΕΡΓΑΚΗΣ), G. S. FTHENAKIS (Γ.Χ. ΦΘΕΝΑΚΗΣ), G. ARSENOS (Γ. ΑΡΣΕΝΟΣ)

Research article
Ερευνητικό άρθρο

Clinical characteristics of lameness and potential risk factors in intensive and semi-intensive dairy sheep flocks in Greece

Gelasakis A.I.[1], Oikonomou G.[2], Bicalho R.C.[2], Valergakis G.E.[1], Fthenakis G.C.[3], Arsenos G.[1]

[1]*Laboratory of Animal Husbandry, School of Veterinary Medicine, Aristotle University of Thessaloniki, Thessaloniki, Greece*

[2]*Department of Population Medicine and Diagnostic Sciences, College of Veterinary Medicine, Cornell University, Ithaca, USA*

[3]*Veterinary Faculty, University of Thessaly, Karditsa, Greece*

Κλινικά χαρακτηριστικά και παράγοντες προδιάθεσης για εκδήλωση χωλότητας σε εντατικές και ημι-εντατικές εκτροφές προβάτων γαλακτοπαραγωγικής κατεύθυνσης στην Ελλάδα

Γελασάκης Α.Ι.[1], Οικονόμου Γ.[2], Bicalho R.C.[2], Βαλεργάκης Γ.Ε.[1], Φθενάκης Γ.Χ.[3], Αρσένος Γ.[1]

[1]*Εργαστήριο Ζωοτεχνίας, Κτηνιατρική Σχολή, Αριστοτέλειο Πανεπιστήμιο Θεσσαλονίκης, Θεσσαλονίκη*

[2]*Department of Population Medicine and Diagnostic Sciences, College of Veterinary Medicine, Cornell University, Ithaca, USA*

[3]*Τμήμα Κτηνιατρικής, Πανεπιστήμιο Θεσσαλίας, Καρδίτσα*

ABSTRACT. Objectives of the study were to present descriptive epidemiological characteristics of lameness in intensively and semi-intensively reared flocks of Chios-breed dairy sheep in Greece, as well as to identify potential factors that may affect development, severity and duration of the disorder. In total, 1618 ewes in nine flocks were used for assessment of locomotion score and detailed clinical examination, which were performed fortnightly throughout a milking period. Subsequently, two logistic regression models were employed to assess impact of various variables on occurrence and severity of lameness. Mean lameness incidence in the nine flocks under surveillance during the milking period was 6.8% (110 cases in 1618 ewes); between flocks range of the incidence was 0.4%-22.0%. In 48% of the cases, lameness was considered to

be severe. Foot-rot was found to be the commonest lameness-causing disorder, accounting for 66% of all cases. During the investigation, incidence of lameness in relation to the causing factor was 4.5% for foot-rot, 1% for white line abscesses, 1% for white line disease, <0.5% for pedal joint abscesses and <0.5% for hoof injuries. Farm size, stocking density, parity of the ewes and lambing season were identified as significant risk factors for dairy sheep lameness occurrence. Finally, stocking density was also found to affect lameness severity.

Keywords: Chios breed, dairy sheep, lameness, risk factors

ΠΕΡΙΛΗΨΗ. Η μελέτη αποσκοπούσε στην περιγραφή των επιδημιολογικών χαρακτηριστικών της χωλότητας σε εντατικές και ημι-εντατικές εκτροφές προβάτων της φυλής Χίου στην Ελλάδα, καθώς και στην καταγραφή παραγόντων προδιάθεσης για τη συχνότητα εκδήλωσης και για τη βαρύτητα της παθολογικής κατάστασης. Συνολικά, στη μελέτη περιελήφθησαν 1618 προβατίνες από εννέα εκτροφές, στις οποίες γινόταν εκτίμηση του δείκτη κινητικότητας και λεπτομερής κλινική εξέταση κάθε δύο εβδομάδες στη διάρκεια μίας γαλακτικής περιόδου. Αναπτύχθηκαν δύο πρότυπα λογιστικής παλινδρόμησης για τη διερεύνηση ποικίλων μεταβλητών στη συχνότητα εκδήλωσης και στη βαρύτητα της νόσου. Η μέση συχνότητα εκδήλωσης χωλότητας, στις εννέα εκτροφές κατά τη διάρκεια μίας γαλακτικής περιόδου ήταν 6,8% (110 περιστατικά χωλότητας στις 1618 προβατίνες της έρευνας), κυμαινόταν δε από 0,4% έως 22,0% μεταξύ των εκτροφών. Σε ποσοστό 48% των περιστατικών, η χωλότητα θεωρήθηκε ως σοβαρή. Η λοιμώδης ποδοδερματίτιδα ήταν η συνηθέστερη αιτία χωλότητας, συγκεκριμένα σε 66% των συνολικών περιστατικών. Η μέση συχνότητα εκδήλωσης χωλότητας ανά αιτία αυτής ήταν 4,5% για τη λοιμώδη ποδοδερματίτιδα, 1% για τα αποστήματα της λευκής γραμμής, 1% για τη νόσο της λευκής γραμμής, <0,5% για τα αποστήματα της δεύτερης μεσοφαλαγγικής διάρθρωσης και <0,5% για τους τραυματισμούς των χηλών. Το μέγεθος της εκτροφής, ο συνωστισμός των ζώων σε αυτήν, ο αριθμός της γαλακτικής περιόδου των προβατίνων και η εποχή του τοκετού βρέθηκε ότι αποτελούσαν σημαντικούς παράγοντες κινδύνου για την εκδήλωση χωλότητας. Τέλος, ο συνωστισμός των ζώων βρέθηκε ότι επηρέαζε τη βαρύτητα της παθολογικής κατάστασης.

Λέξεις ευρετηρίασης: γαλακτοπαραγωγή, παράγοντες προδιάθεσης, φυλή Χίου, χωλότητα

INTRODUCTION

Lameness is a term used to describe a broad spectrum of locomotion disorders that result in gait abnormalities or in conditions where weight bearing by one or more limbs is compromised. In sheep, lameness is predominantly associated with hoof lesions. To date, research has focused on foot-rot, interdigital dermatitis and, more recently, contagious ovine digital dermatitis and was carried out in meat or wool producing breeds (Winter, 2004; 2009; Wassink et al., 2010; Hodgkinson, 2010). Studies have indicated a strong negative effect of lameness on animal welfare, production output (meat, wool), and reproduction efficiency (Stewart et al., 1984; Marshall et al., 1991; Eze, 2002). Other lameness-causing disorders of sheep, such as white line disease, white line abscesses and pedal joint abscesses have not been thoroughly investigated (Conington et al., 2010).

There is a paucity of relevant studies in dairy sheep. Nevertheless, lameness can be of particular importance for dairy sheep around the world. A recent study performed in Chios-breed sheep indicated that lameness was associated with a 20% reduction in milk yield (Gelasakis et al., 2010a). Descriptive epidemiology studies and potential risk factors assessments for lameness have not been carried out in dairy sheep farms. However, there are distinct differences in husbandry practices between meat and dairy sheep production systems and these may contribute to development of lameness related disorders. Moreover, environmental and climatic factors may also be of importance; within Europe, meat-producing sheep are farmed mainly in the north of the continent, whilst dairy sheep are mostly farmed in more southern and para-Mediterranean countries.

Objectives of this work were to present descriptive epidemiological characteristics of lameness in intensive and semi-intensive Chios-breed dairy sheep farms in Greece, as well as to identify potential risk factors for development and severity of the disorder.

MATERIALS AND METHODS

On-farm investigation

In a previously conducted study, 66 Chios dairy sheep farms were surveyed. The collected data and the produced typology of the studied farms have been previously described by Gelasakis et al. (2010b, 2012). For the needs of the present study, k-means cluster analysis (Steinley, 2006) was used for the selection of a representative sample of these 66 farms. Flock size, stocking density and access to pasture were the grouping factors. Flock size was determined by the number of ewes in the farm, stocking density was defined as the available area (m^2) per ewe inside the sheep shed and access to pasture was defined as grazing or zerograzing. The farms were assigned into eight clusters, of which three were recognised as dominant (comprising ≥10 farms). Three farms from each dominant cluster were randomly selected for further investigation. In total, nine farms, comprised 1,618 ewes, were selected. Data regarding parity number, age at lambing and date of lambing were obtained for these farms.

Each of the nine farms was visited by the principal author (AIG) every fortnight throughout a milking period (after weaning of lambs until cessation of lactation and onset of dry period), from January to July 2008. A designated single line passageway was constructed in each farm to facilitate observation of locomotion of individual ewes on their way to the milking parlour, enabling the assessment of presence and severity of lameness. On each visit, each ewe was assigned a locomotion score using the five-point system of Ley et al. (1994) (1: normal gait, 2: no obvious lameness when standing, occasional limping when walking, 3: lifting foot while standing and moderate lameness when walking, 4: shifting stance and severe lameness when walking, 5: unwilling to bear weight on one foot when standing or walking). Ewes with score ≥2 were marked and were subsequently subjected to a detailed clinical examination. Ewes with clinical evidence of other pathological conditions were excluded from the study. A detailed and comparative examination of legs and hoofs was carried out and the diagnosis of causes of lameness was performed as described by Winter (2004).

Data management and analysis

In total, complete history data (parity number, age at previous lambing, date of previous lambing) were available for 1,119 ewes, which were included in the below described models.

A binary logistic regression model (model 1) was developed in order to assess impact of lambing season (2 levels, 1: early lambing, October to December, 2: late lambing, January to March), pasture use (2 levels, 1: grazing, 2: zero grazing), stocking density (2 levels, 1: <2 m^2/ewe, 2: ≥2 m^2/ewe), parity number (4 levels, 1: 1st, 2: 2nd, 3: 3rd, 4: >3rd parity - adjusted for age at lambing) and flock size (continuous variable) on lameness occurrence.

An ordinal logistic regression model (model 2) was built to evaluate the effects of lambing season (2 levels, 1: early lambing, October to December, 2: late lambing, January to March), pasture use (2 levels, 1: grazing, 2: zero grazing), stocking density (2 levels, 1: <2 m^2/ewe, 2: ≥2 m^2/ewe), parity number (2 levels, 1: 1st or 2nd parity, 2: >2nd parity - adjusted for age at lambing) and flock size (continuous variable) on locomotion score. Three levels of locomotion score were used (0: locomotion score 1, 1: locomotion score 2 or 3, 2: locomotion score 4 or 5); the locomotion score assigned on the initial examination of the animal was taken into account and subsequent changes (increase or decrease of score, coinciding with deterioration or improvement of the condition) were not considered.

In Model 1, the Omnibus test was used, in order to test the predicting value of the model versus a model including only the intercept. Goodness of fit was tested using Hosmer and Lemeshow test providing information concerning adequacy of data fitted into the model. Model fitting information and goodness of fit was also calculated for Model 2. Parity number was set at 2 levels, to improve goodness of fit of Model 2. Moreover and in order to test the assumption that regression coefficients were the same across the different categories of the depended variable (locomotion score), test of parallelism was used.

Statistical significance was set at $P < 0.05$. All statistical analyses were performed using PASW© Statistics 18 (SPSS Inc., Chicago, IL).

RESULTS

Mean incidence risk of lameness in the nine flocks during the studied lactation period was 6.8% (110 cases in 1618 examined ewes). Between flocks range

Table 1. Causes of lameness in intensive and semi-intensive Chios-breed dairy sheep flocks in Greece.

Cause of lameness	Number of cases diagnosed	Incidence risk
Foot rot	73	4.5%
White-line abscesses	18	1.1%
White-line disease	13	0.8%
Pedal joint abscesses	3	0.2%
Injuries	3	0.2%
Total	110	6.8%

of the incidence risk was 0.4%-22.0%. Most cases of lameness (69%) were first recorded during the first four months after lambing; mean interval from lambing to first occurrence of lameness of 108±44.5 days. Lameness incidence was higher during the period February to April (52% of all cases recorded) and smaller during July (2% of all ewes were affected).

Lameness was diagnosed more often in the hind legs (60% of ewes with the disease) than in the front legs (40% of ewes). More often, it involved only one claw of the affected foot (75% of cases; in 63% of these cases inner claw affected, in 37% of these cases outer claw affected), rather than both claws of the same foot (25% of cases). More specifically, localisation of lesions causing lameness was as below: rear leg/inner claw 28% of all ewes affected, rear leg/outer claw 17% of all ewes affected, rear leg/both claws 15%, front leg/inner claw 19%, front leg/outer claw 11%, front leg/both claws 10%.

With regard to severity of the condition, in 48% of lame ewes lameness was found to be severe (locomotion score 4 or 5). In 42% of ewes it was considered to be mild (locomotion score 2 or 3) and in 10% of ewes it was considered to be slight (locomotion score 1).

Of the various lameness causes, foot-rot was the main one and accounted for 66% of all cases of the pathological condition. White-line abscesses, white-line disease, pedal joint abscesses and injuries were also diagnosed (16%, 12%, 3% and 3% of all ewes affected, respectively). Information regarding incidence risk of the various lameness causing diseases is presented in Table 1.

In model 1, the Omnibus test was significant: $\chi^2 = 85.02$ (7 degrees of freedom; $P < 0.001$), predicting better the outcome variable in comparison to the model including intercept only; goodness of fit was adequate ($P = 0.506$). Effects of different categorical variables on the odds of lameness are shown in Table 2. Stocking density, flock size, lambing season and parity number were found to be significantly associated with the occurrence of lameness. Ewes housed in a space of <2 m^2 per ewe were at 2.31 times higher odds of developing lameness than ewes kept in a space of >2 m^2 ($P = 0.005$). Nevertheless, grazing was not found to have a statistically significant effect on development of lameness ($P = 0.127$). Effect of flock size was also significant ($P = 0.014$). Additionally, ewes that lambed during the period from January to March were at 1.59 times higher odds to develop lameness than ewes lambing during the period from October to December ($P = 0.044$). The effect of parity number was also statistically significant ($P < 0.001$). When comparisons were made with 1st parity ewes (reference category), 2nd parity ewes were 18.87 times more likely to develop lameness; ewes in their 3rd parity were 6.44 times more likely to develop lameness and 4th parity ewes were 6.77 times more likely to develop lameness.

Model fitting information produced a significant result for model 2, indicating that the model actually improved the prediction ability comparing to a model with intercept only: $\chi^2 = 26.207$ (5 degrees of freedom; $P < 0.001$). Additionally, a non-significant result was produced when goodness of fit was used (both for Pearson, $P = 0.116$, and deviance, $P = 0.368$), suggesting that the data fitted the model well, whereas the test of parallelism: $\chi^2 = 6.966$ (5 degrees of freedom) was not significant ($P = 0.223$) and, hence, the assumption of parallelism was accepted. Effects of different categorical variables on severity of lameness

Table 2. Effects of different variables on development of lameness, as assessed by using a multivariable logistic regression model for data analysis.

Variable	Category	No	Adjusted lameness incidence risk	Odds ratio	P
Parity	1st	253	1.19	[Ref.]	<0.001
	2nd	390	18.46	18.87	
	3rd	223	7.17	6.44	
	4th	253	7.51	6.77	
Lambing season	Early lambing (Oct.-Dec.)	694	8.21	[Ref.]	0.044
	Late lambing (Jan.-Mar.)	425	12.47	1.59	
Pasture use	Yes	356	7.02	[Ref.]	0.127
	No	763	11.14	1.65	
Stocking density	<2m^2 per ewe	526	6.40	[Ref.]	0.005
	≥2m^2 per ewe	593	13.69	2.31	

Table 3. Effects of different variables on severity of lameness, as assessed by using a multivariable logistic regression model for data analysis.

Variable	Category	Odds ratio	Adjusted probabilities			P
			LS 1	LS 2	LS 3	
Parity	1st and 2nd	[Ref.]	88.8	6.3	4.9	0.150
	3rd and 4th	0.96	92.0	4.6	3.4	
Lambing season	Early lambing (Oct.-Dec.)	0.75	91.7	4.7	3.6	0.222
	Late lambing (Jan.-Mar.)	[Ref.]	87.6	6.9	5.5	
Pasture use	Yes	1.86	88.9	6.2	4.9	0.317
	No	[Ref.]	92.9	4.0	3.1	
Stocking density	<2m^2 per ewe	3.37	86.2	7.7	6.1	<0.001
	>2m^2 per ewe	[Ref.]	93.7	3.6	2.7	

LS 1: locomotion score 1, LS 2: locomotion score 2 or 3, LS 3: locomotion score 4 or 5.

are presented in 3. The only variable in this model with a significant ($P < 0.001$) effect on lameness severity was stocking density; when available space per ewe inside the sheep shed was $<2\ m^2$, an increase in lameness severity by one category was 3.37 times more likely than when the available space per ewe was $> 2\ m^2$.

DISCUSSION

To the best of our knowledge, this is the first large scale epidemiological study of lameness in dairy sheep. Lameness incidence risk was found to be 6.8%. Information obtained during previous studies that we had performed, have suggested that farmers, despite considering lameness a significant issue in their flocks, underestimated its incidence (Gelasakis et al., 2008). Similar findings have been reported in meat sheep in Great Britain (Clements et al., 2002; Lewis, 2006). Given the negative impact of lameness on dairy sheep milk production (Gelasakis et al., 2010a), lameness incidence risk reported here suggest that, in dairy sheep, the problem is significant and needs to be addressed. However, it seems that it is not as important as for the modern dairy cow industry (Espejo et al., 2006; Espejo and Endres, 2007); for example, Cook (2003) and Bicalho et al. (2009) have reported lameness prevalence in dairy cattle of 24% and 48%, respectively. In any case, extrapolation of dairy cow results to sheep is often inappropriate and a series of explanations could account for the lower incidence in dairy sheep. These include the lower body weight of that species, the possible differences between the two species regarding the biomechanics of the claw and the differences in management (e.g., extensive use of concrete flooring in dairy cows).

High stocking density was identified as a potential risk factor for increased development and severity of lameness. In Southern European countries, during winter, sheep are kept indoors and have restricted access to paddocks. Decreased availability of space ($<2\ m^2$) in the shed coupled with inadequate ventilation and inadequate bedding material (Gelasakis et al., 2010b) can lead to increased humidity in the shed. Furthermore, the combination of low ambient temperatures ($<15\ ^oC$) and high relative humidity ($>70\ \%$) can be associated with decreased water evaporation from straw bedding. That, coupled with manure accumulation, contamination of bedding and insufficient disinfection inside the barn during winter months would result in compromised hygiene, which favours proliferation and transmission of pathogens, such as *Dichelobacter nodosus* and *Fusobacterium necrophorum*. Such conditions are considered to be prime risk factor for development of foot-rot (Abbott and Lewis, 2005; Green and George, 2008; Sargison, 2008) and provide an explanation regarding seasonality of the increased risk for lameness development during winter months, which has been previously reported by other researchers (Graham and Egerton, 1968; Eze, 2002).

Increased flock size was associated, in the present study, with decreased lameness development. This might be a result of more effective management applied in large, more-commercially oriented, flocks. Kaler and Green (2008) found no association between flock size and lameness incidence in meat sheep in the United Kingdom. However, direct comparisons with the results of our study are difficult, due to the differences in production systems (meat sheep *versus* dairy sheep) and the socio-economic structure of the farming industry (United Kingdom *versus* Greece).

Chios-breed ewes have the highest milk yield during the 2nd lactation period (Gelasakis et al., 2010a), which could partially explain the increased risk of lameness for those animals. That may be associated with increased metabolic requirements of ewes during that period. Considering the plethora of research data from dairy cows, it becomes evident that incidence risk of lameness in dairy cow herds increases, following closely the patterns of increased milk yield, intensification of husbandry practices and genetic improvement. In our view, a broad interpretation of the underlying mechanisms of lameness in sheep is needed. Hence, lameness should be considered as one of the consequences of metabolic problems related to management mistakes, deficiency or excess of nutrients, in particular of micronutrients involved in enzyme and hormone systems. Increased milk production is associated with increased metabolic demands, which if not met, would lead to failure of body organs or tissues. The prevailing view is that foot-rot, the commonest specific disease causing lameness in sheep, can have various clinical presentations (from benign to extremely severe), depending on the strain of *D. nodosus* involved, the immunological status of the animals, the climate and the flock management (Wassink et al., 2004).

In the studied flocks, the strains of *D. nodosus* were not recognized; in general, there is no avail-

able data regarding strains of the organism prevailing and causing disease in Greece. Nevertheless, a high diversity at the ovine *MHC-DQA2* gene locus, which modulates immune response of sheep to foot-rot, has recently been identified in Chios-breed sheep (Gelasakis et al., 2013). Allele *1101* was found to be associated with increased susceptibility to foot-rot. Regarding the climate, it could be assumed that the mild and relatively humid climate of northern Greece, generally favours the occurrence of foot-rot during wet season; in contrast, summers, when ewes are at the dry-period (Petridis et al., 2012; 2013) may be exploited to control the problem. Implementation of preventive measures against foot-rot, within a holistic on-farm management plan for the control of infectious diseases (Fthenakis et al., 2012), could be effective in terms of reducing the incidence and severity of foot-rot-related lameness; thus, it should be evaluated as a possible option.

CONCLUDING REMARKS

Foot-rot was found to be the main cause of lameness in Chios-breed dairy sheep in Greece. Mean incidence risk of lameness was found to be ~7%, indicating it as an important health problem in dairy sheep. Increased stocking density in the farm and parity of ewes have been identified as significant risk factors for the pathological condition.

ACKNOWLEDGEMENTS

CONFLICT OF INTEREST STATEMENT

The authors report no conflict of interest.

REFERENCES

Abbott KA, Lewis CJ (2005) Current approaches to the management of ovine footrot. Vet J 169:28-41.

Bicalho RC, Machado VS, Caixeta LS (2009) Lameness in dairy cattle: A debilitating disease or a disease of debilitated cattle? A cross-sectional study of lameness prevalence and thickness of the digital cushion. J Dairy Sci 92:3175-3184.

Clements ACA, Mellor DJ, Fitzpatrick JL (2002) Reporting of sheep lameness conditions to veterinarians in the Scottish Borders. Vet Rec 150:815-817.

Conington J, Nicoll L, Mitchell S, Bünger L (2010) Characterization of white line degeneration in sheep and evidence for genetic influences on its occurrence. Vet Res Comm 34:481-489.

Cook NB (2003) Prevalence of lameness among dairy cattle in Wisconsin as a function of housing type and stall surface. J Am Vet Med Assoc 223:1324-1328.

Espejo LA, Endres MI (2007) Herd-level risk factors for lameness in high-producing holstein cows housed in freestall barns. J Dairy Sci 90:306-314.

Espejo LA, Endres MI, Salfer JA (2006). Prevalence of lameness in high-producing holstein cows housed in freestall barns in Minnesota. J Dairy Sci 89:3052-3058.

Eze CA (2002) Lameness and reproductive performance in small ruminants in Nsukka Area of the Enugu State, Nigeria. Small Rumin Res 44:263-267.

Fthenakis GC, Arsenos G, Brozos C, Fragkou IA, Giadinis ND, Giannenas I, Mavrogianni VS, Papadopoulos E, Valasi I (2012) Health management of ewes during pregnancy. Anim Reprod Sci 130:198-212.

Gelasakis AI, Arsenos G, Hickford J, Zhou H, Psifidi A, Valergakis GE, Banos G (2013) Polymorphism of the *MHC-DQA2* gene in the Chios dairy sheep population and its association with footrot. Liv Sci 153:56-59.

Gelasakis AI, Arsenos G, Valergakis GE, Fortomaris P, Banos G (2008) Prevalence of lameness in commercial dairy flocks of Chios sheep in Greece. Proceedings of the BSAS annual conference (Scarborough, UK), p. 101.

Gelasakis AI, Arsenos G, Valergakis GE, Fortomaris P, Banos G (2010a) Effect of lameness on milk production in a flock of dairy sheep. Vet Rec 167:533-534.

Gelasakis, AI, Valergakis GE, Arsenos G, Banos G (2012) Description and typology of intensive Chios dairy sheep farms in Greece. J Dairy Sci 95:3070-3079.

Gelasakis AI, Valergakis GE, Fortomaris P, Arsenos G (2010b) Farm conditions and production methods in Chios sheep flocks. J Hell Vet Med Soc 61:111-119.

Graham NPH, Egerton JR (1968) Pathogenesis of ovine foot-rot: the role of some environmental factors. Aust Vet J 44:235-240.

Green LE, George TRN (2008) Assessment of current knowledge of footrot in sheep with particular reference to *Dichelobacter nodosus* and implications for elimination or control strategies for sheep in Great Britain. Vet J 175:173-178.

Hodgkinson O (2010) The importance of feet examination in sheep health management. Small Rumin Res 92:67-71.

Kaler J, Green LE (2008) Recognition of lameness and decisions to catch for inspection among sheep farmers and specialists in GB. BMC Vet Res 4:41-49.

Lewis CJ (2006) Footrot and interdigital dermatitis in sheep. Vet Rec 158:71-72.

Ley SJ, Waterman AE, Livingston A, Parkinson TJ (1994) Effects of chronic pain associated with lameness on plasma cortisol concentrations in sheep: a field study. Res Vet Sci 57:332-335.

Marshall DJ, Walker RI, Cullis BR, Luff MF (1991) The effect of footrot on body weight and wool growth of sheep. Aust Vet J 68:45-49.

Petridis IG, Mavrogianni VS, Gougoulis DA, Amiridis GS, Brozos C, Fthenakis GC (2012) Effects of drying-off procedure of ewes' udder, with intramammary antibiotic administration, in subsequent mammary infection and development of mastitis. J Hell Vet Med Soc 63:273-282.

Petridis IG, Mavrogianni VS, Fragkou IA, Gougoulis DA, Tzora A, Fotou K, Skoufos I, Amiridis GS, Brozos C, Fthenakis GC (2013) Effects of drying-off procedure of ewes' udder in subsequent mammary infection and development of mastitis. Small Rumin Res 110:128-132.

Sargison N (2008) Sheep Flock Health - A Planned Approach. Blackwell, Oxford.

Steinley D (2006) K-means clustering: a half-century synthesis. Br J Math Stat Psych 59:1-34.

Stewart DJ, Clark BL, Jarrett RG (1984). Difference between strains of *Bacteroides nodosus* in their effects on the severity of footrot, body weight and wool growth in Merino sheep. Aust Vet J 61:348-352.

Wassink GJ, George TR, Kaler J, Green LE (2010) Footrot and interdigital dermatitis in sheep: farmer satisfaction with current management, their ideal management and sources used to adopt new strategies. Prev Vet Med 96:65-73.

Wassink GJ, Grogono-Thomas R, Moore LJ, Green LE (2004) Risk factors associated with the prevalence of interdigital dermatitis in sheep from 1999 to 2000. Vet Rec 154:551-555.

Winter AC (2004) Lameness in Sheep. Crowood Press, Marlborough.

Winter AC (2009) Footrot control and eradication (elimination) strategies. Small Rumin Res 85:90-93.