Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1133500

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 5 - Issue 4: 357-364 / October 2022

STATISTICAL ANALYSIS OF LAMB SURVIVAL DURING THE REARING PERIOD WITH THE USE OF CLASSIFICATION TREES AND LOGISTIC REGRESSION

Dariusz PIWCZYŃSKI[1]*, Julia PIWCZYŃSKA[2], Magdalena KOLENDA[1]

[1]*Bydgoszcz University of Science and Technology, Faculty o Animal Breeding and Biology, Department of Animal Biotechnology and Genetics, 85-084, Bydgoszcz, Poland*
[2]*Wrocław University of Environmental and Life Sciences, Faculty of Veterinary Medicine, 50-375, Wrocław, Poland*

Abstract: The presented research aimed to statistically analyse the survival of 44,133 Polish Merino and Polish Merino in Old-Type lambs between birth and the 100th day of their life, using classification trees and logistic regression. The study included lambs born between 2008 and 2017 and used in 43 flocks in Pomerania and Kujawy region (Poland). The results showed that 9.27% of all controlled lambs did not survive till the 100th day of life. The statistical analysis of the case of lambs' death during their first 100 days of life was carried out using multiple logistic regression as well as classification trees, using two algorithms CART and CHAID. The quality of multiple regression and decision tree models was compared considering the following criteria: percentage of misclassifications, average squared error and the area under the Receiver Operating Characteristic curve. The calculated quality criteria for tree models that were created during the research suggested that the classification trees formed based on CART algorithm were the most accurate in defining the variability of studied characteristics, i.e. survival of lambs up to the 100th day of age. For the best available classification model, the ranking of variable importance, developed based on the "Importance" measure, allowed to conclude that the type of lamb's birth, season, following by the year of birth, subsequent lambing, lamb's sex and its breed were the most significant differentiating factors. It was noted that the tree built with the use of CART algorithm was composed of 30 leaves. It was also shown that the highest frequency of lamb's death during the rearing period was to be expected among triplets born in winter or summer (37.14% of all deaths), while the highest chance (98.42%) of surviving till the 100th day of life showed singletons, born from their mother's 3rd to 6th litter, in the spring-winter season in the last year of the present research.

Keywords: Lamb mortality, Classification tree, CART, CHAID, Logistic regression

***Corresponding author:** Bydgoszcz University of Science and Technology, Faculty o Animal Breeding and Biology, Department of Animal Biotechnology and Genetics, 85-084, Bydgoszcz, Poland
E mail: darekp@pbs.edu.pl (D. PIWCZYŃSKI)
Dariusz PIWCZYŃSKI https://orcid.org/0000-0001-8298-2316
Julia PIWCZYŃSKA https://orcid.org/0000-0002-6650-0150
Magdalena KOLENDA https://orcid.org/0000-0002-9260-4391

Received: June 21, 2022
Accepted: July 05, 2022
Published: October 01, 2022

Cite as: Piwczyński D, Piwczyńska J, Kolenda M. 2022. Statistical analysis of lamb survival during the rearing period with the use of classification trees and logistic regressions. BSJ Agri, 5(4): 357-364.

1. Introduction

The beginnings of Polish Merino breeding in Poland date back to the 1870s. In the 1990s Polish Merino was improved by crossbreeding with prolific breeds, therefore, the number of sheep of the pure breed decreased considerably (Gut et al., 2008). In consequence, in 2008 the Polish Merino population (breed) was distinguished to represent the original breed pattern – Polish Merino in Old-Type (MPS) (maintains the breed purity) (PSBA, 2009). The Polish Merino is a breed that is normally used for two purposes: wool and meat. As measured in 2008, the ewes under assessment had an average prolificacy of 128.3%, while the average rearing for lambs until the age of approximately 100 days equaled 90.9%. In December 2020 the sheep population in Poland amounted to 277.9 thousand heads, including 148.7 thousand ewes (GUS, 2021). In the racial structure of ewes under the performance assessment, 1.71% were of Polish Merino (MP) breed and 10.39% of Old-Type Polish Merino (PSBA, 2021).

Lamb mortality resulting in high losses inevitably leads to a significant decrease in how profitable the production of sheep is. Hence, it is essential to discover the factors that are behind this. The common practice in Poland is to register lamb mortality but without specifying the time of death. This produces a binomial piece of information: 1 for the lamb that survived until the end of the rearing period, 0 for the deceased lamb. The statistical analysis of this type of trait is usually carried out with the use of logistic regression (Piwczyński, 2007, Schreurs et al., 2010; Piwczyński et al., 2012, Piwczyński et al., 2013a;). A possible alternative to logistic regression may be the classification tree technique (Piwczyński et al., 2012). It is an analytical technique that belongs to the field of data mining. The same field includes the cluster analysis and artificial neural networks (Grzesiak, 2003; Piwczyński et al., 2013a). The classification trees techniques have reportedly been used many times in animal farming and breeding throughout the past several years (Piwczyński et al., 2012, Piwczyński et al., 2013a, Piwczyński et al., 2013b; Ghiasi et al., 2019; Kliś et al., 2021;). When graphical models of classification trees are created, this results in the occurrence of distinguishable subsets, having a "T" shape, within the repeated split of the set of observations (Piwczyński et al., 2013b). The reason for doing this is to obtain subsets that will have the highest possible homogeneity as regards a dependant variable's value. The same independent variables do not have to be used at various stages of the data set's multi-trait splitting. The variable that is selected is the one that warrants the best possible split of a node, which in turn results in the most homogeneous sets. The first thing one needs to do when forming a classification tree is to look at an entire data set, which is called the root node here. Subsequent nodes that occur as a result of splitting are known as child nodes. The name of a subset without any further division is a leaf. The measurement of each tree is made based on the number of its leaves. A tree's depth is determined by how many edges there are from its top to the leaves located furthest away.

The aim of the research was a statistical analysis of lamb mortality between their birth and the weaning time, using two algorithms of classification trees building (CART, CHAID), and comparison of obtained results with the results from logistic regression.

2. Material and Methods

The study included 44133 lambs born between 2008 and 2017 and used in 43 flocks in Pomerania and Kujawy region (Poland). The animals were maintained using indoor livestock farming. The data were obtained from breeding documentation from the Regional Association of Sheep and Goat Breeders, Bydgoszcz.

Table 1 presents statistical characteristics of the analyzed population in terms of lamb mortality in the period from birth to weaning (~100 days), depending on the examined factor: lambs' breed (MP, MPS), lambs' gender (ram, ewe) and type of birth (single, twine, triplet), dams' birth type (single, twin, triplet), subsequent lambing (1…8), year (2008-2017) and season of lambing (spring – III, IV, V; summer – VI, VII, VIII; autumn – IX, X, XI, winter – XII, I, II).

Table 1. Mortality of lambs classified by various factors

Factor	Level	Number of born lambs	Mortality (%)	Prob.
Breed of lamb	MP	15744	9.39	0.5328
	MPS	28789	9.21	
Gender of lambs	Ewe	22242	8.66	<0.0001
	Ram	22291	9.88	
Type of lamb birth	1	26259	6.03	<0.0001
	2	17831	13.58	
	3	443	28.22	
Type of dam birth	1	23045	9.13	0.5609
	2	20969	9.43	
	3	519	9.06	
Subsequent lambing	1	1509	12.99	<0.0001
	2	4021	9.65	
	3	4854	7.97	
	4	5736	8.47	
	5	6329	7.99	
	6	5110	9.43	
	7	4778	9.27	
	8	12196	10.18	
Year of lambing	2008	4896	8.17	<0.0001
	2009	4485	8.23	
	2010	3811	8.21	
	2011	4227	10.15	
	2012	4448	9.82	
	2013	4482	10.49	
	2014	4389	9.5	
	2015	4751	10.9	
	2016	4707	9.67	
	2017	4337	7.4	
Season of lambing	Spring	2122	11.26	<0.0001
	Summer	9542	9.00	
	Autumn	22470	8.22	
	Winter	10399	11.39	
	Total	44533	9.27	

The statistical analysis of the case of lambs' death during their first 100 days of life was analyzed using the chi-square test. Later multiple logistic regression as well as classification tree (using two algorithms CART and CHAID) were used. The classification tree technique was used to establish the factors that were to blame for the variability in lamb mortality. There were 44133 observations, of which 60% were used in the training set, and the other 40% formed the validation set. Stratified random sampling was applied to create the sets. The tree was formed using the former, whereas the latter was used for cutting. An assumption was made that the final node can have a size no lower than 100 observations, and that the maximum depth is 6. Such rules concerning leaf size and depth were selected so that overfitting of the tree to the training data was avoided – this could be a reflection of random links occurring inside the validation set. Each node that was formed and the resulting leaf were accompanied by the following details: ID (1); mortality percentage (2), and how many observations there were in a node or leaf (3) (Figure 1).

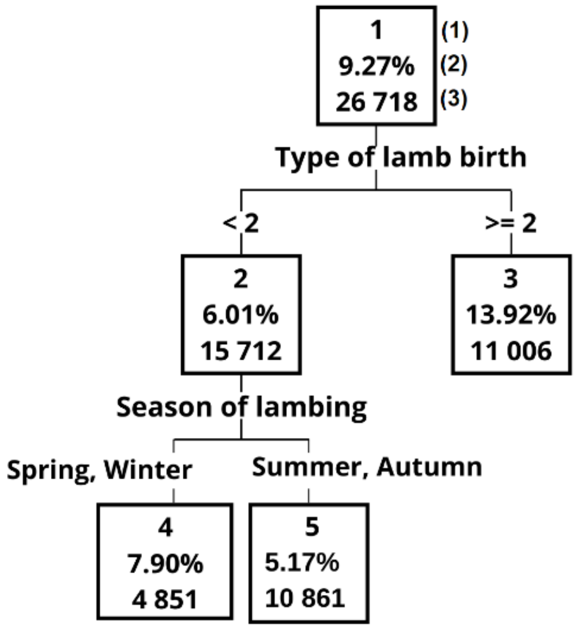

Figure 1. The graphical model of the classification tree - part 1.

Variables were ranked according to their importance for the creation of data set splits, with the use of the "Importance" measure (SAS Institute Inc., 2021). To calculate this measure (I(v,T) (Equation 1), a square root of the product of the Gini coefficient reduction (ΔGini) needs to be used. This, in turn, is calculated using the main and surrogate splits which in all nodes of the tree have the v variable (T), as well as the "agreement" measure ($a(s_v, t)$) connected with the rule that uses the v variable in the t node:

$$I(v,T) = \sqrt{\sum_{t=1}^{T} \Delta Gini(s(v,t))\, a(s_v,t)} \quad (1)$$

where: s(v, t) – the best surrogate split in the t node using the v variable (Equation 2)

$$a(s_v,t) = \begin{cases} 1 & \text{if } s_v \text{ is the main splitting rule} \\ \text{agreement} & \text{if } s_v \text{ is the surrogate rule} \\ 0 & \text{Otherwise} \end{cases} \quad (2)$$

The values for the „agreement" measure are taken from the (0,1) range. This measure shows the share of agreeing on cases upon the comparison of the main and surrogate splits. The measures of "Importance" established for each variable were divided by the "importance" variable that had the highest importance.

This was followed by the verification of the effect of the factors under examination on lamb survival, conducted with the use of multiple logistic regression (SAS Institute Inc., 2021). The main factors were taken into consideration in the model, as were its interactions second degree. The forward method was used to determine statistical variables connected with lamb mortality. Wald statistics (SAS Institute Inc., 2021) were used to evaluate the importance of individual parameters within a model.

The quality of multiple regression and decision tree models was compared considering the following criteria: percentage of misclassifications, average squared error and the area under the Receiver Operating Characteristic curve. Statistical analysis was carried out using the Enterprise Miner 15.1 software included in the SAS package.

3. Results

The results showed that 9.27% of all controlled lambs did not survive till the 100th day of life (Table 1). The preliminary chi-square test showed that the mortality of lambs in the rearing period was highly significantly influenced by the influence of sex and birth type of lambs, dam's birth type, next lambing season, season and year of lambing. It was observed that the mortality of MPS lambs was 0.18 percentage points (pp) lower than MP, ewes by 1.22 pp. than rams. It was also observed that lambs from twin births were characterized by a higher risk of death during the rearing period and that the most deaths of lambs were recorded in the first and last of the studied reproductive periods. It was also shown that lamb mortality varied from one year to the next (from 7.4 to 10.90% and during the lambing season (from 8.22% to 11.39%) (Table 1).

The improvement in the quality of a given logistic and classification tree models can be proved based on a decrease in the values of the average squared error; misclassification rate; an increase in the values of the lift cumulative Kolmogorov-Smirnov statistics; and the area below the ROC curve (ROC index). Therefore, one may conclude that the classification trees formed based on CART algorithm were the most accurate in defining the variability of studied characteristics, i.e. survival of lambs up to the 100th day of age (Table 2). For his model (CART), the ranking of variable importance, developed based on the "Importance" measure, allowed to conclude that the type of lamb's birth, season, following by the year of birth, subsequent lambing, lamb's gender and its breed were the most significant differentiating factors (Table 3).

Table 2. Model comparisons

Measure	CART	CHAID	Logistic regression
Average squared error	0.0819	0.0822	0.0823
Cumulative lift	2.1071	1.9743	2.0563
Kolmogorov-Smirnov statistic	0.2280	0.2260	0.2240
Misclasification rate	0.0928	0.0928	0.0931
ROC index	0.6540	0.6400	0.6500

Table 3. Variable importance and number of splits

Variable	Number of splits	Importance
Type of lamb's birth	2	1.000
Season of lambing	5	0.411
Year of lambing	10	0.334
Subsequent lambing	8	0.299
Gender	3	0.171
Breed	1	0.083
Type of dam's birth	1	0.052

It was noted that the tree built with the use of CART algorithm was composed of 30 leaves (Figures 1-4). In creating the tree, the largest number of splits was based on the following variables: year (10 splits) and subsequent of lambing (8), the season of lambing (5 splits), gender of lambs (3 splits) and type of lamb's birth (2 splits). In turn, variables breed of lamb and type of dam's birth were used once by the tree forming algorithm.

It should be emphasized that the results are shown in the nodes constituting the decision tree come only from the training set. Due to the complex nature of the tree, only the major splits were described in the study. The first and most important split of the lamb mortality dataset was based on the type of birth (Figure 1). As a result, subsets of lambs were created: from a single (Node 2) and multiple (Node 3) births, which were characterized by mortality of 6.01 and 13.29%, respectively. A further split of the set of lambs from multiple pregnancies (Node 3) was again based on the lamb's type of birth. It led to the separation of a subset of lambs from twin pregnancies (Node 6) with mortality of 13.53% and triplet pregnancies (Node 7) with mortality equal to 29.20% (Figure 4). Further divisions were also presented in provided Figures.

It was shown that in the construction of the classification tree the variable called calving year was used the greatest number of times (participated in 10 splits) by the CART algorithm, but the resulting subsets do not allow for the identification of unambiguous trends concerning the influence of this factor on lamb mortality. Multiple divisions of data subsets based on the mother's next litter allow concluding that lambs born to the youngest and oldest ewes (Node 30, 52, 56, 27, 37, 83) were characterized by higher mortality in the rearing period than those born from 2 to 7. at once (Node 31, 52, 53, 26, 36, 82). It was also observed that the rams (Node 10, 29, 5) had higher mortality than the ewes (Node 11, 28, 51) during the rearing period, and the differences ranged from 1.05 to 4.27 pp. It was also found that lambs of the MPS breed (Node 23) were characterized by 1.65 pp. lower mortality than MP (Node 22). Moreover, it was shown that lambs born to ewes from single litters (Node 38) were characterized by 1.85 pp. greater mortality than in multiple litters.

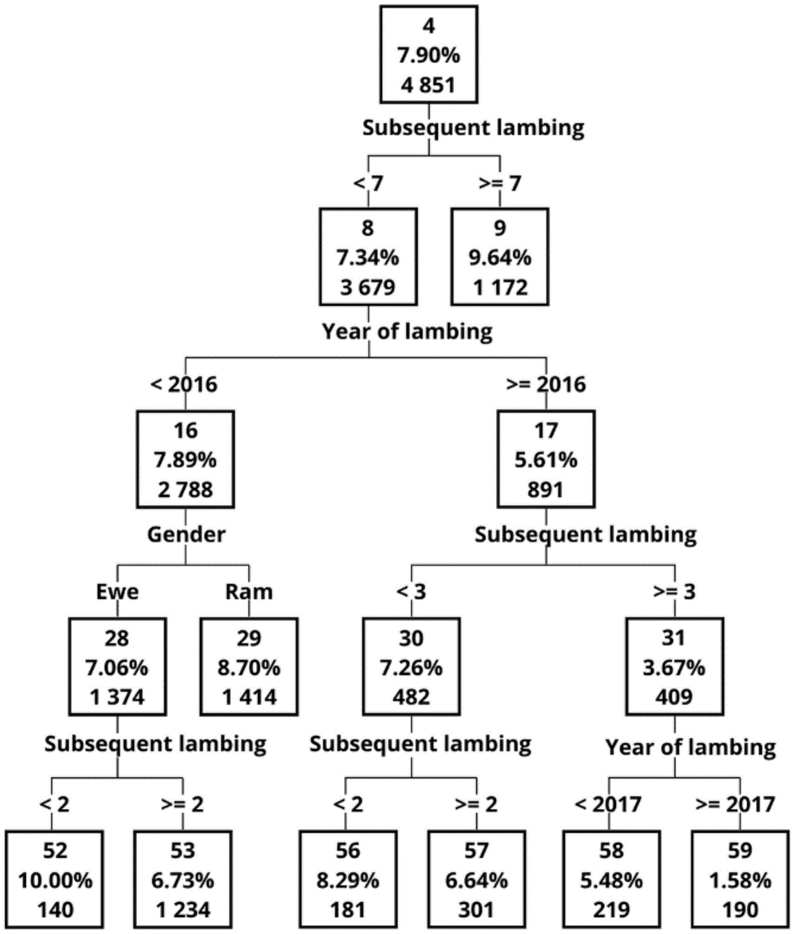

Figure 2. The graphical model of the classification tree - part 2.

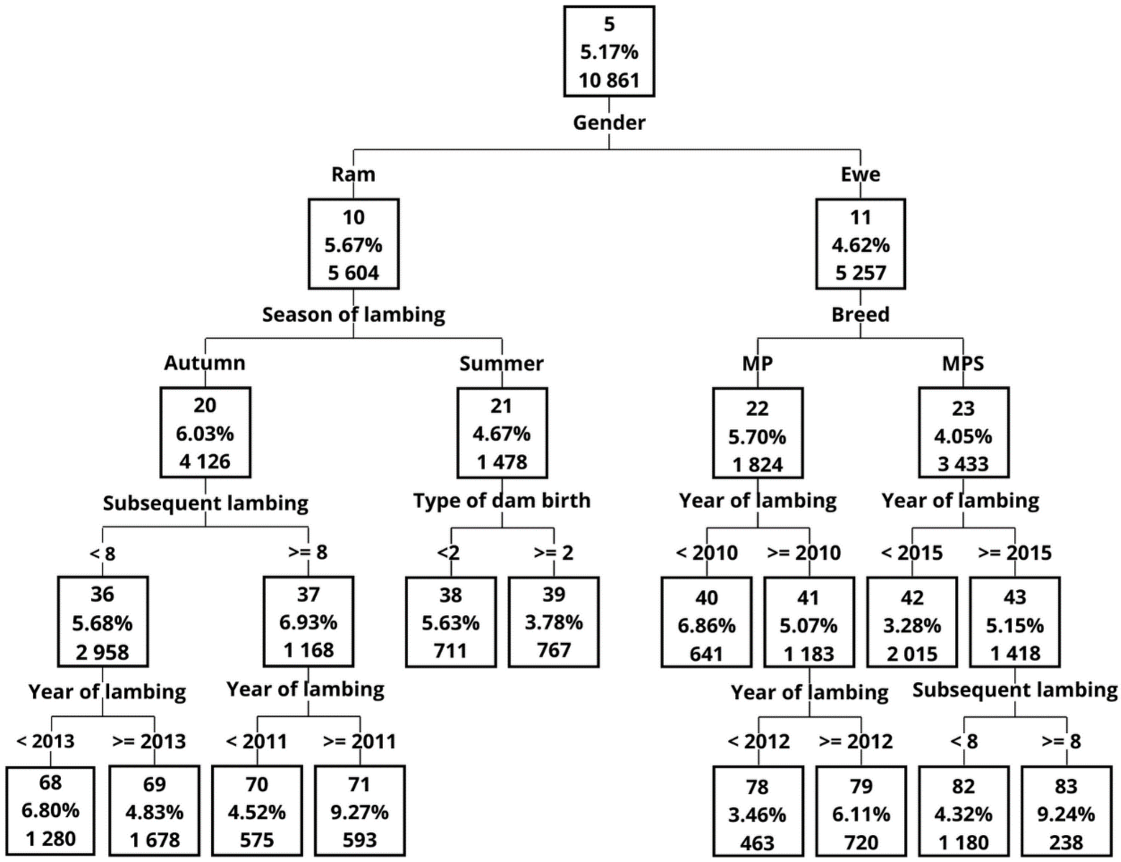

Figure 3. The graphical model of the classification tree - part 3.

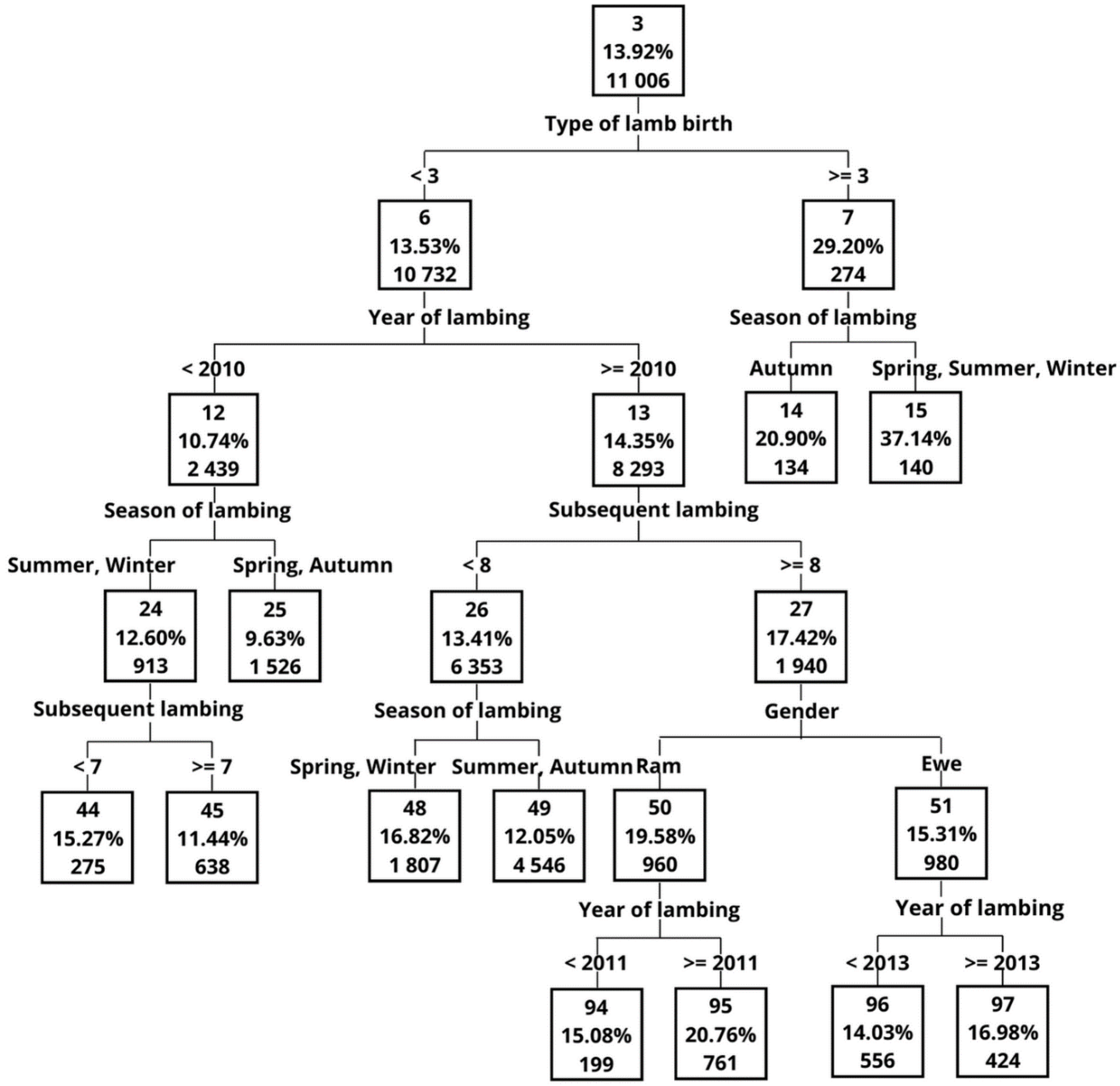

Figure 4. The graphical model of the classification tree — part 4.

4. Discussion

The percentage of lambs mortality kept in the Pomerania and Kuyawy region, in our research (9.27%) can be considered as slightly higher than for MP and MPS populations in all country. The Polish Sheep and Goat Breeders Association (PSBA, 2009) cites a corresponding index for the population of the Polish Merino in the year 2008 at 9.10%. In turn, the corresponding indicator for MP in 2020 was 6.5%, and MPS - 6.4% (PSBA, 2021). In earlier research (Piwczyński, 2007; Piwczyński, 2012), the observed proportion of Polish Merino lamb deaths in the period from birth to 100 days of age varied in the range of 6.74-9.19%.

Lamb mortality in the present study compared to other studies is proven to be relatively low. Hatcher et al. (2009) and Campbell et al. (2009) found mortality of the Australian Merino lambs in the weaning period (110 days) to be as high as an average of 14.3-27.6%. On the other hand, Cetin and Akcapnar (2005) found mortality in the range of 10.10% to 19.97% for Merino lambs. The climate in which the population of the assessed Polish Merino sheep were kept was a mild one. The fact that lamb mortality was low might suggest that the breeding conditions were favorable for the animals. Furthermore, it could be understood as proof that the applied breeding processes are effective as far as lamb survival is concerned. Mortality results obtained by some authors (Milerski, 2006; Hatcher et al., 2009) for different breeds of lamb, kept in different climatic conditions, signal possible considerable variations in terms of this trait between individual populations.

ROC index was one of the quality criteria chosen in respect of the classification tree and logistic regression models. Based on the values obtained for this index (0.650 to 0.654), it can be said that the prognostic capability in the case of all the models is moderate. A similar value of this index was established in studies on lamb mortality by Piwczyński et al. (2012) (0.6090-0.6476); on stillbirths Polish Holstein-Freisan calves by Piwczyński et al. (2013a) (0.6110) as well as in the work by Ghiasi et al. (2019) on modelling conception to first service (0.629-0.6323).

The research showed that the type of birth was the most important factor differentiating the mortality of lambs. The death rate for twins was twice as high as for singletons and for triplets four times as high as for the group of singleons. This is also confirmed by research by Piwczyński (2007), Aksakal et al. (2009), Hatcher et al. (2009), Piwczyński et al. (2012) have shown that the risk of death rises for twins. This tendency is supported by the results of our research. The reason for this is the lower weight of twins at birth, and also their more difficult access to udders, and contact with the dam. The type of birth is typically associated with body weight – it is lower in twins. The impact of body weight at birth on lamb mortality was shown in research conducted by Casellas et al. (2007), and Schreurs et al. (2010) – it was observed that both low as well as too high body weight at birth increase the risk of death.

According to Petersson and Danell (1985), the lambing season is a significant factor influencing lamb mortality. In the present research, this factor was indicated by the algorithm creating the classification tree as the second most important factor differentiating lambs in terms of their survival rate. The studies showed that lower mortality of lambs was observed among those born in the autumn and summer months than in the winter and spring months, which can be justified by a better feed base and more favorable climatic conditions at that time.

It was established by the authors that the year of birth was a key factor in variations in terms of the mortality of lambs. This may reflect different maintenance conditions, ways of feeding, and breeding work intensity. Evidence provided in studies by Petersson and Danell (1985), Mandal et al. (2007), Piwczyński et al. (2012), Everest-Hincks et al. (2014), supports the assumption that the year of birth has a statistical effect on lamb mortality. Moreover, the findings of our research as regards the impact of the lambing dam's age on the mortality among its offspring have been confirmed by what was established in the studies conducted by Petersson and Danell (1985), Aksakal et al. (2009), Hatcher et al. (2009), Salem et al. (2009). The results in the offspring of young female lambs were found to have been the least favourable in this respect. At the same time, in our research, we observed increasing mortality of lambs born to mothers in their 8th litter compared to previous, which can be justified by the deterioration of milk yield among these mothers.

It is not completely clear whether the lamb's sex has any effect on mortality. In our research, the classification treeS technique has revealed varied mortality among ewes and rams during the rearing period. Petersson and Danell (1985) had found comparable lamb mortality for both sexes; and the same had been established by Piwczyński et al. (2012). On the other hand, studies conducted by Hatcher et al. (2009), Morel et al. (2009), Everest-Hincks et al. (2014) indicate that mortality in ram lambs is considerably higher, which has also been confirmed in current studies; while Aksakal et al. (2009), who examined the Awassi breed, as well as Piwczyński (2007), in an earlier study on MP, found the mortality to be higher among ewe lambs.

The literature on the subject indicates many factors are responsible for lamb mortality in the period between birth and weaning. Results obtained by Freking and Leymaster (2004), Ekiz and Altnel (2006), Milerski (2006) prove that the mortality of lambs may be breed related. In our research, we found that MPS lambs had lower mortality in the rearing period than MP, which can be explained by the good maternal instinct of this breed. It should be emphasized, however, that the chi-square test conducted in the preliminary statistical analysis did not show a statistical relationship between breed and lamb mortality, and the value of the "Importance" measure of the "breed" variable was only 0.083. The dam's birth type played an even smaller role (Importance 0.052; $P_{chi\text{-}square} > 0.05$) than the breed of lamb in the structure of the classification tree, which is consistent with the results obtained in previous studies (Piwczyński et al. 2012). It should be noted, however, that in the current studies, lower mortality of offspring was observed among mothers from multiple births than in single births.

The undeniable advantage of the classification tree technique is the ability to study complex relationships between the variables responsible for the variability of the dependent variable (Piwczyński et al. 2013b). The result of our research showed that the highest frequency of lamb's death during the rearing period was to be expected among triplets born in winter or summer (37.14% of all deaths) (Node 15), while the highest chance (98.42%) of surviving till the 100th day of life showed singletons, born from their mother's 3rd to 6th litter, in the spring-winter season in the last year of the present research (Node 59).

5. Conclusion

The research showed that among the compared models of data analysis, the classification tree model based on the CART algorithm best predicted the mortality of lambs during the rearing period. In turn, the variables most strongly associated with the mortality of lambs were, in the order of decreasing importance: the type of lamb's birth. Season of lambing, year of lambing and subsequent lambing.

It was also shown that the highest frequency of lamb's death during the rearing period was to be expected among triplets born in winter or summer (37.14% of all deaths), while the highest chance (98.42%) of surviving till the 100th day of life showed singletons, born from their mother's 3rd to 6th litter, in the spring-winter season in the last year of the present research.

The advantage of using classification trees is that they present information in a clear graphic way, which makes it possible to understand splits which at times may be very complex. A graphical model of a tree created based on the Gini contamination indices is a proof of the presence of several interactions between different factors.

Author Contributions

D.P. (100%) initiated the research idea, developed (100%), organized (100%), analyzed (100%) and interpreted the data (50%) and wrote the manuscript (30%); J.P. interpreted the data (50%) and wrote the manuscript (30%); M.K. wrote the manuscript (40%). All authors reviewed and approved final version of the manuscript.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans. The analyzed data on lamb mortality were taken from breeding documentation from the Regional Association of Sheep and Goat Breeders, Bydgoszcz.

Acknowledgments

We would like to thank the Regional Sheep and Goat Breeders Association in Bydgoszcz (Poland) for providing data for the research.

References

Aksakal V, Macit M, Esenbuga N, Dogan KA. 2009. Effects of various ages of weaning on growth characteristics, survival rate and some body measurements of Awassi lambs. J Anim Vet Advan, 8(80): 1624-1630.

Campbell A, Vizard A, Larsen J. 2009. Risk factor for post-weaning mortality of Merino sheep in south-eastern Australia. Aust Vet J, 87: 305-312.

Casellas J, Caja G, Such X, Piedrafita J. 2007. Survival analysis from birth to slaughter of Ripollesa lambs under semi-intensive management. J Anim Sci, 85: 512-517.

Cetin H, Akcapnar H. 2005. The effects of twice lambing in a year on the survival ability and growth of Merino lambs. Lalahan Hayv Araş Enst Derg, 45(2): 25-34.

Ekiz B, Atnel A. 2006. The growth and survival characteristics of lambs produced by commercial crossbreeding Kivircik ewes with F2 rams with the German Black-Headed Mutton genotype. Turk J Vet Anim Sci, 30(6): 507-512.

Everett-Hincks JM, Mathias-Davis HC, Greer GJ, Auvray BA, Dodds KG. 2014. Genetic parameters for lamb birth weight, survival and death risk traits. J Anim Sci, 92(7): 2885–2895.

Freking BA, Leymaster KA. 2004. Evaluation of Dorset, Finnsheep, Romanov, Texel, and Montadale breeds of sheep: IV. Survival, growth, and carcass traits of F1 lambs. J Anim Sci, 82(11): 3144-3153.

Ghiasi H, Sadeghi-Sefidmazgi A, Taherkhani R, Khaldari M, Piwczyński D. 2019. Application of classification tree method to determine factors affecting somatic cell count in Holstein cows. J Agr Sci Tech, 21(7): 1783-1792.

Grzesiak W. 2003. Milk yield prediction in cows with artificial neural network. Pr Mat Zoot, 61: 71-89.

GUS. 2021. Central Statistical Office - Farm animals in 2020. URL: https://stat.gov.pl/en/topics/agriculture-forestry/animal-production-farm-animals/farm-animals-in-2020,1,3.html (access date: June 02, 2022).

Gut A, Wójtkowski J, Ślósarz P, Pietrzak J. 2008. Conservation breeding of old type Polish Merino Sheep. Rocz Nauk PTZ, 35(1): 19-23.

Hatcher S, Atkins KD, Safari E. 2009. Phenotypic aspects of lamb survival in Australian Merino sheep. J Anim Sci, 87: 2781-2790.

Kleemann DO, Walker SK. 2005. Fertility in South Australian commercial Merino flocks: relationships between reproductive traits and environmental cues. Theriogenology, 63: 2416-2433.

Kliś P, Piwczyński D, Sawa A, Sitkowska B. 2021. Prediction of lactational milk yield of cows based on data recorded by AMS during the periparturient period. Animals, 11(2): 383. DOI: 10.3390/ani11020383.

Mandal A, Prasad H, Kumar A, Roy R, Sharma N. 2007. Factors associated with lamb mortalities in Muzaffarnagari sheep. Small Rum Res, 71(1-3): 273-279.

Milerski M. 2006. Analysis of lamb mortality in Sumava, Suffolk, Charollais, Romney, Merinolandschaft and Romanov sheep in the Czech Republic. Book of Abstracts, EAAP – 57th Annual Meeting, September 17-20, 2006, Antayla, Turkey, pp: 215.

Morel PCH, Morris ST, Kenyon PR. 2009. Effects of birth weight on survival in twin born lambs. Proc New Zealand Soc Anim Prod, 69: 75-79.

Petersson CJ, Danell Ö. 1985. Factors influencing lambs survival in four Swedish sheep breeds. Acta Agric Scand, 35: 217-232.

Piwczyński D. 2007. Statistical analysis of lamb mortality using logistic regression. Rocz Nauk PTZ, 3(1): 19-26.

Piwczyński D, Nogalski Z, Sitkowska B. 2013a. Statistical modeling of calving ease and stillbirths in dairy cattle using the classification tree technique. Livest Sci, 154: 19-27.

Piwczyński D, Sitkowska B, Czajkowska A. 2013b. Application of data mining techniques in biological research. Biotechnology and Animal Food Quality. Part III. SAAIC – Erasmus intensive program, Bydgoszcz, Poland, pp: 89-98

Piwczyński D, Sitkowska B, Wiśniewska E. 2012. Application of classification trees and logistic regression to determine factors responsible for lamb mortality. Small Rum Res, 103(2): 225-231.

PSBA. 2009. Sheep and goats breeding in Poland in 2008, 2020. The Polish Sheep Breeders' Association, Warsaw (in Polish).

PSBA. 2021. Sheep and goats breeding in Poland in 2008, 2020. The Polish Sheep Breeders' Association, Warsaw (in Polish).

Salem IB, Rekik M, Hammami H, Hamouda MB, Aloulou R, Sâadoun L. 2009. Fateurs de variation non génétique de la productivité des brebis de race Noire de Thibar. Revue Élev Méd Vét Pays Trop, 62(1): 59-66.

SAS Institute Inc. 2021. Getting started with SAS ® Enterprise Miner 15.1TM. Cary, NC: SAS Institute Inc.

Schreurs NM, Kenyon PR, Mulvaney FJ, Morel PCH, West DM, Morris ST. 2010. Effect of birth weight and birth rank on the survival of single and twin lambs born to ewe lambs. Anim Prod Sci, 50(5-6): 460-464.