

IMPACT OF THE HOUSING SYSTEM AND APPLIED PRECISION TECHNOLOGIES ON PRODUCTIVE AND REPRODUCTIVE INDICATORS IN DAIRY HERDS

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Supporting Information



ABSTRACT: The objective of this study is to examine the associations of the number of applied precision technologies, housing systems, and 3.6%-fat-standardized milk yield groups with the farm-level average duration of the service period and the average semen doses per conception. For the purpose, a survey was held in 2025 by direct standardized interview among 180 owners of cattle farms in Bulgaria and the gathered information was analyzed by one-way analysis of variance (ANOVA). The results showed that high average daily milk yield over 30 kg was associated with a longer service period of 126 days, while for farms with low productivity (up to 20 kg) it was the shortest 102.17 days. Farms with tie-stall housing maintained the shortest service period (104.69 days) but showed lower conception efficiency, requiring a higher mean of 3.73 semen doses per conception. On the other hand, in free-stall housing, the service period was the longest (129.79 days), but the lowest mean of 3.26 doses per conception was recorded. The implementation of three or more precision technologies optimized reproductive management, demonstrating a lower mean of 3.36 doses per conception, whereas farms using only one or two technologies utilized a higher number of 3.71 and 3.75 doses, respectively. In conclusion, high farm-level productivity does not inevitably compromise fertility, provided that intensive milk production is balanced with precise technological monitoring and strategic management decisions.

Keywords: Precision livestock farming, dairy farms, service period, number of doses for insemination, housing system.

INTRODUCTION

In recent years, dairy cattle farming has undergone large-scale transformation aimed at increasing milk productivity from cows. An example of this is the United States, where the Holstein breed reaches levels of 12,934 kg of milk produced per cow (Bórawski et al., 2021; Ruban et al., 2023). However, the absolute leader in intensive production worldwide remains Israel with an average annual milk yield of 13,112.80 kg (Bayramoğlu and Esen, 2025). In the European Union, the average productivity is about 7,208 kg, while Denmark reports levels of up to 9,504 kg (International Scientific Days 2020, 2020). Despite the drive for modernization, Bulgaria's indicators remain significantly lower than the European average. With a yield of around 3,640 kg of milk per cow, our country achieves less than 50% of the EU average (Kubala and Stanuch, 2023). While the national average is low, studies in various intensive farms in Bulgaria show a radically different picture. Studies of structural convergence in the EU have found that in countries like Bulgaria the sector is divided into two clearly defined poles. The first one encompasses a large proportion of small farms with a yield of around 3,000 kg, and the second one includes modernizing farms, whose productivity has stabilized around 7,500 kg and continues to grow (Jong et al., 2019).

A study by Karamfilov and Kanev (2025) on Holstein cattle in Southern Bulgaria for the period 2019–2023 reported an average lactation milk yield of 10,840 kg, with some farms exceeding 12,150 kg per animal. This is almost three times the national average.

This focus on milk yield, according to Ruban et al. (2023), presents modern cattle breeding with a critical paradox: approaching the genetic ceiling of production can be associated with high metabolic demands, which may affect their health and compromises their reproductive capacity. Britt et al. (2021) emphasize that in the highest-producing herds, the management of physiological stress is a key factor in preventing reproductive problems. With just 15.4% of the world's dairy cows producing nearly 45% of the global milk supply, the enormous pressure on these animals requires constant monitoring of their welfare. This is further emphasized by recent regional findings demonstrating the necessity of routine screening even in traditional production frameworks, where 60% of 196 analyzed milk samples exceeded a threshold of 500,000 somatic cells/mL (Mevliyaogullari & Göncü, 2025a).

Overcoming these economic and biological challenges, is only possible through the full digitalization of farms. Precision livestock farming offers automated monitoring systems that replace subjective visual observation. State-of-the-

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art developments in the field of computer vision, using YOLOv5 algorithms, allow the identification of behavioral signs of estrus with an accuracy of 97.6%, even under difficult lighting conditions in the barn (Clayton et al., 2025). According to Patel et al. (2026), the integration of these digital technologies is the only way to achieve “smart” and sustainable dairy production that balances high milk yield with reproductive health.

The aim of the present study is to analyze the differences in the farm-level average duration of the service period and the average number of semen doses per conception among different precision technology classes, housing systems, and fat-standardized milk yield (FSMY) groups.

MATERIALS AND METHODS

Design and Data Collection

For the purpose of the study, a survey was conducted among 180 owners of cattle farms from all over the country with different farm capacities in the period from 01 Jan 2025 to 31 Dec 2025. The survey included a total of 80 questions related to general characteristics of the farms, productive and reproductive indicators, technologies and technological equipment, animal nutrition and health, etc. The empirical information was collected through direct standardized face-to-face interviews. All respondents were asked the same questions in the same sequence. Strict instructions were used, which allowed the collection of comparable data across the surveyed farms. The data were gathered through a non-probability convenience sampling approach utilizing the PAPI (Pen and Paper Interview) format, which ensured objectivity and a high degree of control over the interviewing process. The individual information gathered in this way was entered in the form of electronic records and analyzed using selected statistical and mathematical methods. For some groups of indicators, the data were taken from the farm documents (productive and reproductive indicators, number of cattle by category, etc.).

Grouping and Factor Classes

Since the cows are of different breeds both between farms and within individual herds, milk fat content exhibits natural fluctuations depending on both the breed and the lactation stage. As demonstrated by Mevliyaogullari and Gönçü (2025a), milk fat traits change significantly during weeks 2–32 of lactation even under identical dietary rations. Therefore, to reduce the effect of the breed and the lactation stage on the milk productivity parameters, the farm-level mean daily milk yield was converted to a 3.6%-fat-standardized milk yield (FSMY) using the formula:

$$\text{FSMY (kg)} = (\text{daily milk yield (kg)} \times \text{fat content (\%)}) / 3.6$$

For a better approximation, the average daily FSMY was categorized into three factor classes, as follows: 1 – up to 20 kg, 2 – from 20 to 30 kg, and 3 – over 30 kg. A total of 19 advanced precision electronic components and technical solutions were evaluated in the survey, and the owners indicated which options were implemented on their farms. For statistical analysis, each component was documented as a binary variable (1 = present, 0 = absent) to represent the total number of distinct advanced systems utilized. These items comprised automated milking helpers (including milk meters, automatic cup detachers, conductivity and temperature indicators), computerized tracking software (including herd logs, electronic tags, pedometers, neck collars, rumen boluses), and precision feeding automation (including concentrate stations, smart wagon mixer scales, automated calf feeders). Due to the distribution of responses, the farms were classified into four consistent categories based on their advanced technology counts: Class 0 (none are used), Class 1 (one device), Class 2 (two devices), and Class 3 (three or more devices).

Statistical analysis

Data management and graphical illustrations were performed using MS Excel. Descriptive statistics and analysis of variance (ANOVA) were conducted using the relevant modules of STATISTICA by StatSoft (Copyright 1984–2011, StatSoft, Inc.). To evaluate the impact of individual factors, the following one-way ANOVA model was applied:

$$Y_{ij} = \mu + A_i + e_{ij}$$

where Y_{ij} is the dependent variable (service period and mean number of semen doses per conception, analyzed at farm level); μ is the overall mean of the trait; A_i is the fixed effect of the studied factor class (housing system, applied precision technologies, or FSMY group); e_{ij} is the random effect of factors not included in the model.

For each trait, the least squares means were estimated for each class of the fixed factors from the corresponding analysis of variance model. The variations among these classes were evaluated based on the sums of squares, calculated as the deviations from the overall mean value of the trait obtained from the model.

RESULTS AND DISCUSSION

Table 1 presents the descriptive statistical metrics for the studied productive and reproductive parameters. The column “Number” reflects the number of farms that provided specific data on the respective indicator within the framework of the survey.

The average service period was 115.37 ± 1.46 days, varying from 73 to 152 days with a standard deviation of 18.76 days. The average number of semen doses per conception was 3.50 ± 0.06 , ranging from 1 to 5 with a standard deviation of 0.72. The FSMY was 28.23 ± 0.56 kg on average, with a standard deviation of 7.51 kg and a variation from 13.73 kg to 49.10 kg. The results obtained about the service period are in line with the research of [Gukezhev et al. \(2025\)](#), according to which in modern high-productivity herds this indicator naturally stabilizes in the range between 115 and 120 days. The author adds that a significant percentage of farms report an average of three to four doses of semen. [Mikolaychik et al. \(2021\)](#) specified that the extension of the period to insemination is a common consequence of the high intensity of milk production and is associated with a higher number of necessary inseminations.

The applied one-factor analysis of variance (Table 2) revealed a significant association between the housing system and the service period ($P < 0.001$) and the semen doses per conception ($P < 0.01$).

Table 1 - Average values and variation of the studied indicators and factors

Parameters	n	$\bar{x} \pm Se$	SD	min - max
Farm-average service period (days)	164	115.37 ± 1.46	18.76	73 - 152
Farm-average semen doses per conception	161	3.50 ± 0.06	0.72	1 - 5
Farm-average daily FSMY (kg)	180	28.23 ± 0.56	7.51	13.73 - 49.10

n = number of reporting farms; FSMY= 3.6%-fat-standardized milk yield; $\bar{x} \pm Se$ = mean $\pm$ standard error; SD = standard deviation

Table 2 - Analysis of variance for the studied operational factors and reproductive parameters

Variation source	Degrees of freedom	Service period			Semen doses per conception		
	df	MS	F	P	MS	F	P
Housing system	2	6861	25.32***		2.48	5.06**	
Precision technologies	3	3165.1	10.58***		1.58	3.29*	
FSMY	2	8437	33.56***		0.66	1.29	

FSMY = 3.6%-fat-standardized milk yield; df = degrees of freedom; MS = mean square; F = F-statistic; P = P-value; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$

A significant effect on the service period ($P < 0.001$) and the semen doses per conception ($P < 0.05$) was also found depending on the number of applied technical devices and sensors. Regarding the factor 3.6%-fat-standardized milk yield (FSMY), significant differences were reported only for the service period ($P < 0.001$), and the effect on the semen doses per conception was not statistically significant. In support of present results, [Bielfeldt et al. \(2004\)](#) found that the housing system (free versus tie) was a statistically significant factor ($P < 0.05$) for reproductive performance, including the success of the first insemination. In addition, [Huba et al. \(2023\)](#) noted that the factors “pasture rearing” and “herd” had a statistical effect ($P < 0.01$) on the trait “number of lactations”. Using ANOVA and F-test, [Palombi et al. \(2013\)](#) found that the introduction of calving monitoring systems had a statistically significant association with the number of inseminations to conception. On the other hand, [Kiyici et al. \(2020\)](#) found in their model that the level of milk production did not differ statistically ($P > 0.05$) in relation to reproductive results (number of inseminations).

The average values for the service period depending on the housing system applied on the farm were presented in Figure 1. The longest average service period was recorded on farms with free-stall housing systems 129.79 days, followed by those with free group housing 115.33 days. The shortest average service period was observed on farms with tie-stall housing 104.69 days. The results obtained are in line with the research of [Naviya et al. \(2025\)](#), who found that in free-range systems, significant variations in this indicator are often observed. In free-stall housing in summer conditions, an average service period of about 121.2 days was recorded, with the detection of estrus and heat stress at the herd level remaining critical factors. [Litvinenko et al. \(2020\)](#) added that in highly productive dairy herds under similar housing systems, the service period often reaches levels of about 130 days, which is frequently associated with a prolonged intercalving period and a decrease in the coefficient of reproductive capacity. [Sivkin and Arutyunyan \(2026\)](#) found that, unlike free systems, tie-stall housing allows for more intensive individual monitoring, which under certain conditions is associated with a shorter service period by 12.0–14.2 days compared to free-range systems.

LS-mean values for the service period depending on the number of precision technologies applied are shown in Figure 2. Farms with the largest number of applied technical devices and sensors (3 and more) had the longest average service period 121.14 days, and the shortest period was recorded on farms without any technologies (Class 0) 97.11 days. This effect is also due to the large difference in the 3.6%-fat-standardized milk yield among these groups. The lowest daily milk yield is on farms that do not use any devices and sensors in their work 23.95 kg.

Morozov (2024), in line with our results, found that in digitalized farms using health control systems, the service period often varies within 128–135 days, which significantly exceeds standard technological norms. Edwards et al. (2026) added that the implementation of additional sensors does not always result in automatic shortening of reproductive intervals, and in some cases there is even an increase in the period to insemination by up to 20 days without a significant improvement in fertility levels. Kleen and Guatteo (2023) noted that the effectiveness of precision livestock farming depends to a large extent on management decisions based on the submitted data, and in less technologically advanced farms, direct visual control of animals still ensures high insemination efficiency. Through correlation analysis ($r = 0.15$) Gorelik et al. (2021) also confirmed that high daily milk yield is consistently associated with an extension of the service period.

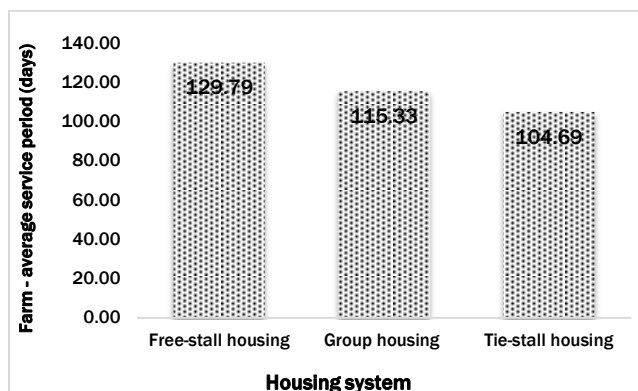


Figure 1 - LS-mean values for the service period depending on the housing systems used on the farm ($F = 25.32$; $P < 0.001$).

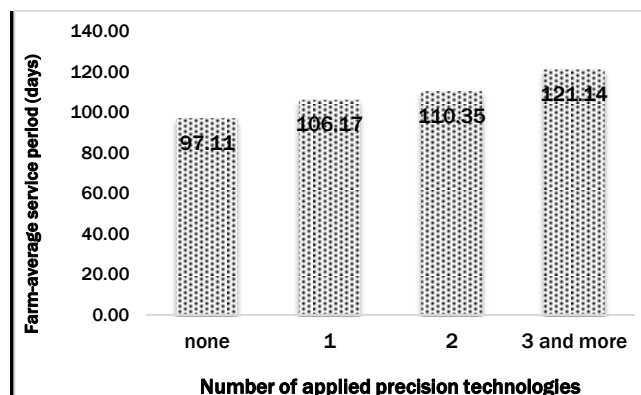


Figure 2 - Farm-average service period (days) depending on the number of applied precision technologies (none, 1, 2, or 3 and more devices; $F = 10.58$; $P < 0.001$).

Regarding the relationship between the service period and the average daily milk yield at the farm level, Figure 3 presents the LS-mean values of the service period depending on the 3.6%-fat-standardized milk yield obtained from the analysis of variance model (Table 2). In farms with the lowest average FSMY up to 20 kg, the service period was the shortest 102.17 days, while in farms with the highest daily milk yield, over 30 kg, the average service period was the longest 126.0 days. This significant relationship supports the assumptions made so far that farms with small capacity, tie-stall housing, and no application of any technical devices and sensors, having low daily milk yield, exhibit a correspondingly shorter service period, while longer service periods characterize large, high-yielding technologically intensive operations.

The difference we found of nearly 24 days in the reproductive interval between groups with different productivity was confirmed by the studies of Amma et al. (2024) who found that the group with the highest milk production had an average of 41.5 days longer service period compared to the group with the lowest productivity. Titova (2021) added that the association of the level of milk yield on the variation of the service period was 5.4%, with each increase in milk yield by about 15% being associated with a longer period to conception by 7.2 days.

That relationship, according to Lepesheva et al. (2023), is explained by the high metabolic demands in high-producing herds. They pointed out that the focus on milk production often led to a “subfertility syndrome”, with the statistical correlation between milk yield and fertility indicators varying widely from $r = -0.2$ to -0.7 . This is consistent with the findings of Mevliyaoğulları and Göncü (2025b), who evaluated early-lactation blood parameters in high- and low-yielding Holstein cows and reported no statistically significant differences between the yield groups, which may suggest that under comparable feeding and housing conditions blood metabolic indicators alone may not reliably reflect milk yield variations at the herd level. Although on the highly productive farms in our study the service period reached 126 days, Grinchuk and Nesterova (2021) noted that in modern conditions, values of 120 to 130 days are considered a physiologically justified adaptation that allows herds to realize their genetic potential for milk production without permanently endangering productive longevity. LS-mean values for the semen doses per conception depending on the applied housing system on the farm are presented in Figure 4.

Although the shortest service period was recorded in farms with tie-stall housing, these herds were reported to have the highest semen doses per conception 3.73, while farms with free-stall housing reported the lowest number of doses used 3.26. These results were supported by the research of Bielfeldt et al. (2004), who found that the percentage of conception from the first attempt in barns with tie-stall housing was significantly lower (about 44%) compared to those with free-stall housing (52%), which was associated with higher semen doses per conception. Livchikov and Shishkina (2025) added that the free-stall system achieved significantly better indicators in terms of insemination frequency compared to tie-stall housing, and the differences were statistically significant. Sudarev and Ivanov (2022) reported that the insemination rate in tie-stall systems was higher by 0.26 to 0.42 units compared to free-stall farms, and Admina et al. (2024) added that the differences in fertility between the two farming systems were highly reliable at significance levels

of $P < 0.001$. LS-mean values for the semen doses per conception depending on the degree of implementation of precision technologies are presented in Figure 5. The lowest number was reported in farms applying three or more technical devices and sensors (3.36 doses), while the highest values were observed in farms using one or two technologies 3.71 and 3.75 doses, respectively.

Krpálková et al. (2020) supported our results by stating that precision technologies not only improved the detection of estrus, but also by determining the moment of insemination resulted in significant improvement in the conception rate and, accordingly, to a reduction in the semen doses per conception. Kaewbang et al. (2024) added that the implementation of biosensors was associated with a statistically significant ($P < 0.01$) increase in the conception rate, and in some farms the probability of success increased nearly fivefold compared to traditional methods. Cavallini et al. (2025) specified that the combination of rumination indicators and 3D accelerometers for activity allowed for a more accurate differentiation of physiological states at the herd level. Lovarelli et al. (2020) found that the larger amount of data collected by multiple devices allowed farmers to avoid errors in estrus detection and reduce the number of required semen doses, which is critical for the economic sustainability of large farms. LS-mean values for the semen doses per conception depending on FSMY are presented in Figure 6.

In farms with the lowest FSMY, below 20 kg per day, a higher number of semen doses per conception were used 3.65 compared to those with daily milk yield above 30 kg, 3.41 doses. The results obtained correspond to the studies of Bayramoğlu and Esen (2025), who found that the average semen doses per conception was lower in large farms compared to small ones. The authors explained this with the better organization and technological management in higher-productive farms, which managed to compensate for the physiological stress from the high milk yield. In contrast to our results, Çağatay et al. (2025) found a highly reliable relationship between milk productivity and reproductive indicators ($P < 0.001$). In their study, the average semen doses per conception was 2.29, indicating that the level of milk yield had a direct association with the number of doses used. The relationship between these factors was further supported by the study of Erzurum and Kayar (2024), who indicated that the number of inseminations was influenced not only by genetic factors, but also by a number of environmental factors. Their data showed that effective herd management allowed maintaining high milk productivity without necessarily leading to an increased number of required semen doses.

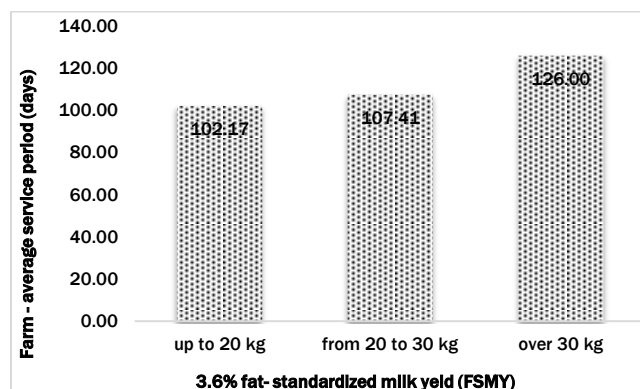


Figure 3 - LS-mean values for the service period depending on FSMY ($F = 33.56$; $P < 0.001$).

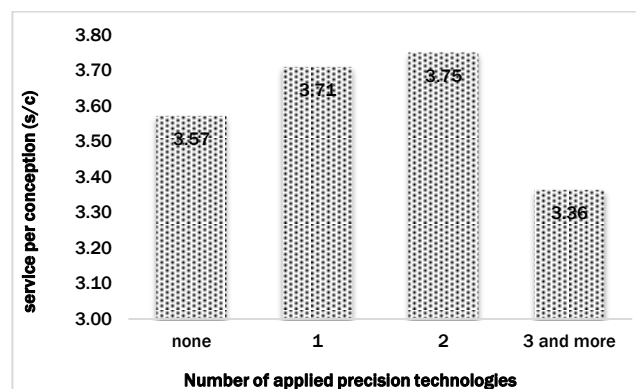


Figure 5 - Semen doses per conception (expressed as services per conception, S/C) depending on the number of applied precision technologies (none, 1, 2, or 3 and more devices; $F = 3.29$; $P < 0.05$).

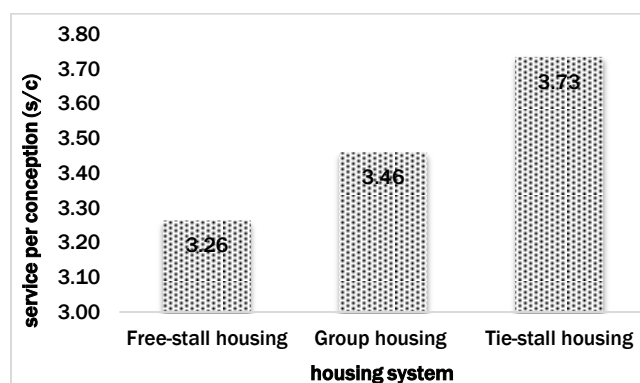


Figure 4 - LS-mean values for semen doses per conception depending on the housing system ($F = 5.06$; $P < 0.01$).

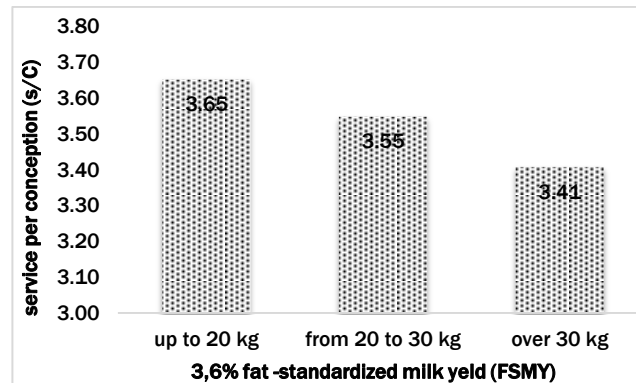


Figure 6 - Semen doses per conception (expressed as service per conception, S/C) depending on the 3.6%-fat-standardized milk yield (FSMY) groups ($F = 0.66$; $P = ns$).

CONCLUSION AND RECOMMENDATION

In conclusion, farm-level average daily FSMY, housing systems, and precision technology implementation significantly influence dairy herd reproductive parameters. A high average daily FSMY (over 30 kg) is associated with a longer service period mean of 126 days, whereas low-productivity farms (up to 20 kg) exhibit the shortest mean of 102.17 days. Regarding infrastructure, tie-stall housing maintains the shortest service period (104.69 days) but requires a higher mean of 3.73 semen doses per conception. Conversely, free-stall housing results in the longest service period (129.79 days) but achieves the lowest mean of 3.26 semen doses per conception. Furthermore, technology adoption optimizes reproductive management; implementing three or more precision technologies reduces semen demand to a mean of 3.36 doses, compared to 3.71 and 3.75 doses when using only one or two technologies, respectively. These results confirm that high farm productivity does not necessarily compromise fertility parameters when combined with precise technological monitoring and strategic management decisions. A limitation of this study is the application of a single-factor framework necessitated by the high multicollinearity among the examined operational factors. Future multivariable research could further clarify the combined associations of housing, technology, and milk yield.

DECLARATIONS

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contribution

Emil Mitev: statistical processing of data, literature review, writing the original text of the manuscript. Yovka Popova: development of the concept and design of the study, analysis and interpretation of the obtained data, and critical revision of the manuscript. Stayka Laleva: supervision of the experiment, resources, final correction and editing of the text. All authors approved the final version of the article and are responsible for the accuracy of the presented data.

Ethical regulations

Formal ethical approval was not required for this study according to the institutional regulations of the Agricultural Institute – Stara Zagora, as the research strictly involved a non-invasive, voluntary survey of farm owners and collected no sensitive biological or personal data. Participation in the surveys and interviews was entirely voluntary, and informed consent was obtained from all respondents prior to data collection. Absolute confidentiality and anonymity of the participants' personal data were guaranteed throughout the study.

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Competing interests

The authors declare that they have no competing interests.

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