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Analysis of Management, Labor and Economics of Milking Systems in Intensive Goat Farms

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Abstract: Dairy goat farms are growing in the world, but their technological level and, particularly, milking equipment are less developed than those of dairy cow farms. This study aims to evaluate milking parlors in the current situation in modern goat farms and suggest possible solutions or improvements. Ten goat farms located in various municipalities of the Friuli-Venezia Giulia region (Northeast Italy) adopting different milking systems (parallel milking parlors, milking carts, and milking buckets) were monitored. The mathematical model developed originally for the evaluation of milking parlors for dairy cows was modified and adapted to goat milking systems. Time for milking and final specific direct costs are the main parameters that enable evaluation and choice of suitable milking parlor; neglect or promotion of only one of the mentioned criteria may lead to an uneconomic investment or impaired operation of a farm. The research results showed that the modern milking systems, with a greater number of stalls and milking clusters, have a greater capacity and require less time for milking a goat than bucket and cart systems. The study also demonstrated that increasing the capacity of dairy goat farms enables a reduction of the final specific costs for milking.

Keywords: dairy goat; milking; housing; equipment; milking parlor; labor; economic analysis

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1. Introduction

In the last few years, goat breeding in countries with intensive agriculture has undergone major and rapid changes, and with it, there has been a need for developing new technologies and modernization of milking systems [1,2]. The capacity of the farms is expanding and increasing the average annual milk production per goat. In Italy are bred little more than 1 million goats, of which 304,777, corresponding to 29.4%, are specialized dairy goats belonging to Sarda, Meticcio, Saanen, and Camosciata delle Alpi breeds (figures updated to December 2021) [3]. Specialized dairy goat farms are 4269 of a total of 51,834 farms, which represent only 8.2%, but in intensive farms are bred 21.8% of the total dairy goats. The average size of one dairy goat farm is 72.8 goats, and the milk production in 2020 was 43,665 t year^{-1} [4], with an average production of 10.2 t year^{-1} farm^{-1}, which means an increase in production of 58% from the previous 5 years. The main destination of goat milk is the cheese factory; in fact, 7420 t year^{-1} of goat cheese are produced in Italy (figures updated to 2019) [5]. In the Italian region of this survey, Friuli-Venezia Giulia, are bred 2075 dairy goats in 39 intensive farms [3], and the prevalent animal breeds are the Camosciata delle Alpi and the Saanen.

Goat farms are steadily changing from extensive to intensive systems, and in some cases, this has led to the abandonment of grazing. To be more competitive, farmers had to increase both quality (partially dependent on the milking system) and quantity: these have led to a progressive modernization of dedicated milking equipment.

According to Alejandro [6], the use of automatic devices in milking parlors for sheep and goats is becoming more common. Automation can reduce milking time, saving labor

force and simplifying milking routine. In combination with animal identification, farmers can register, store, and analyze all animal data coming from milking equipment and other equipment. The main automation equipment that are available for dairy sheep and goat farms are automatic vacuum shut-off, milk recording, electronic identification, flock management software, and sort gates. The above systems can help farmers to reduce overmilking, increase the health status of the animal, save time on daily tasks, and collect necessary info to make the right decision at the right time.

The focus of the investigation of Varlyakov et al. [7] was the milking behavior and the effect of age and productivity of Saanen goats. A strict hierarchical order was established in the herd. The majority of the animals built up a reflex towards the place in the milking parlor, which sometimes resulted in technological problems. The production performance had a lower effect than age on social rank. The effect of age on the four studied traits, milk yield, rate of milk flow, persistence in using a milking place, and order of entering the parlor, was the most pronounced in high-production animals.

Rossel et al. [8] include a list of the main parameters and characteristics for suitable low-cost goat milking equipment for family enterprises, which predominate in the Mexican high plains and other regions of intensive grazing in the world. The milking process and its interaction with all other devices and procedures in a mechanized system are analyzed. The design of a mobile installation for milking goats, adaptable to a wide range of milk production systems, is presented.

Problems with the application of new technologies for milking goats on farms in Portugal are presented in the article of Barbosa et al. [9].

There are two divergent interests in choosing the appropriate milking parlor, that of the manufacturer/dealer who strives for the highest price contract, and that of the farmer who would like to receive the best product, with the price as favorable as possible. The functionality of the milking parlor is one of the essential factors which affect the efficiency of milk production.

Several aspects can be considered in the decision-making process to determine the appropriate type of milking parlor for each farm. The key points to consider are animal welfare, operational capacity, price, number of milkers, the complexity of the operation, reliability, and dimensions. An incorrect evaluation may result in problems during the operation and negatively affect the performance of the farm, in some cases with the unnecessary waste of finance, without any real benefit.

Several authors have presented recommendations focused on the milking characteristics of dairy goats and the use of automatic devices in the milking parlor, debating on performance but not including economic analysis. There are no publications with basic equations for the calculation of several parameters, completed with economic results for goats. Similar calculations are presented for dairy cows, but not in a universal approach that could be adapted for goats.

Some principles of milking parlors and milking procedures are very similar for sheep and goats. The aim of the investigation carried out by Mačuhová et al. [10] was to evaluate how the order in which the sheep in a milking group enter the milking parlor affects their milk ability and milk composition. Some sheep prefer to enter the milking parlor predominantly early, and some prefer in the last groups. The order of the milking parlor group does not affect milk composition and somatic cell count.

The aim of the study of Romero et al. [11] was to discover the effect on the milking of Murciano-Granadina goats over an entire lactation period by using automatic cluster removers, set up with two different combinations of milk flow threshold and delay time, and comparing them with the traditional method using manual cluster removal. Although there were no differences in the sanitary status of the mammary gland and milk composition, the milking with manual cluster removal caused higher teat-end oedema and increased the vacuum drops. It was concluded that these devices could be installed in milking parlors, substituting the manual cluster removal, maintaining the income from milk quantity and quality.

Goats in the Canary Islands are milked once a day, so they are adapted to accommodate large volumes of milk into their cisterns between milkings. Therefore, it is important to know whether the oxytocin released by the stimulation of the mammary gland can increase milk production when the goats are not milked immediately after the stimulation. The research presented by Torres et al. [12] explains that the oxytocin released by the stimulatory effect of milking procedures did not reduce the presence of milk in alveoli on dairy goats not milked immediately. This response is explained by the large storage capacity of the gland cisterns in Majorera goats, which can accommodate the milk let down induced by oxytocin and allow the replacement of milk storage in the alveoli.

The aim of the research carried out by Gomes et al. [13] was to identify etiologic agents and risk factors for mastitis in dairy goats. The biggest risk associated with mammary infection was the hygiene of ceilings, room, milker, and also the process of milking resulting from these microorganisms. Thus, despite indications of hygienic measures in the programs of milk quality and mastitis control, the applicability and awareness of employees involved in the production chain of milk goats are not sensitized. Therefore, personnel training is the principal measure recommended for the control of mastitis in dairy goats.

A study presented by Zaninelli et al. [14] gives a detailed description of the current knowledge of the electrical conductivity of milk as the most studied parameter for detection when applied to milk from dairy goats to identify mastitis cases.

The aim of another study by Zaninelli [15] was to determine the detection potential of electrical conductivity when measured online on a daily basis and compared with readings from previous milkings.

A large-scale survey was conducted on 173 dairy goat farms in Northern Italy to provide an updated view on farm management practices and to investigate relations among management factors, herd traits, and milk yield and quality, with a particular focus on milk somatic cell count (SCC) and milk fat/protein reversion syndrome. The results reported by Sandrucci et al. [16] show that although SCC was not considered a reliable indicator of mastitis in goats, losses of milk associated with the increase in somatic cells suggest the need for greater attention to the problem, in particular in the small farms where sometimes it is difficult to continuously adopt the correct milking procedure. Concerning the reversion syndrome of milk fat and protein, there is a need to better understand the genesis of this phenomenon and its mitigation strategies. The effect of factors other than feeding deserves more attention, particularly the influence of high SCC.

Murciano-Granadina dairy goats (n = 220) were used in research carried out by Carné et al. [17] to assess the performance of visual and electronic identification devices. Leg tags in the hind leg of adult goats offered suitable (>98%) visual and electronic readability. Nevertheless, both the design and inner circumference of the fastened leg tags should be thoroughly evaluated to avoid causing limping, as was observed in some cases of early leg tags application in replacement stock. In this study, standard-sized electronic rumen boluses and electronic button tags did not reach recommended readability rates (>98%) for official identification of goats.

The study by Fabio Napolitano et al. [18] aims to identify margins for the improvement of dairy animal welfare and production based on the quality of the human–animal relationship (HAR). Given that a good-quality HAR may benefit the welfare of dairy animals and productivity, new technologies, by monitoring the handling routine on farm, may be more effective in promoting good practices.

Goat dairy farms in Italy are undergoing rapid growth from traditional small extensive to intensive farms, and milking technology should be modernized, because milking practices and milking performance influence milk quality and udder health status. For these farms, it is useful to evaluate different equipment and operating conditions by selected and uniform criteria.

The milk production sector's current conditions and expected developments highlight a strong need for more efficient and sustainable farming systems [19]. Farmers have to face, on the one hand, ensuring animal welfare and the development of new technologies and

more expensive techniques, and, on the other hand, a strategy to improve farm management and the need to reduce costs. This also applies to goat farms focused on milk production. Therefore, it is important to choose the right decision criteria when creating a model.

There are various practical recommendations in the literature, based on many years of experience, sometimes with results of measurements from farms [20]. Problems of optimal number of clusters per milker are solved in the research work of Hansen [21]. However, sub-economic data that lead to specific figures characterizing the overall result of the milking parlor are not included. Provolo et al. [22,23] present models focused on the choosing of milking parlors, but not with a complete universal approach that could be adapted everywhere. Results of research used for the calculation of several parameters of milking parlors are presented by Gaworski et al. [24]. Results based on the mathematical model focused on the conditions of dairy farms and milking production in the Czech Republic and Latvia are presented by Kic [25,26].

The present paper aims to apply the same model, adapted to parameters valid for Italian goat farms. There are differences between the milking process and equipment used for dairy cows and dairy goats. Small ruminants differ from dairy cattle in mammary gland anatomy, milk's properties, milking routine strategies, and machine milking settings [27]. Unlike milking cows, milking goats is easier because the milk is released faster, the milk volume is much smaller, the goat has only two teats, and the herd size is smaller than on modern large-capacity farms with dairy cows. Conversely to dairy cows, investing in equipment for performing mechanical prestimulation in dairy goats is not needed, as it does not offer any advantage [28].

2. Materials and Methods

2.1. Description of the Model

A mathematical model originally created for dairy cattle milking parlors has been modified for the calculation of goat milking, introducing equations for time measurements applied to groups of goats milked together, and taking into account different technical and construction parameters (e.g., smaller number of milking clusters, different approach of milker, different movements, etc.).

The first step in analyzing the working operations of the machine milking process on a goat farm is to determine the milking parlor capacity, which is determined by Equation (1).

$$Q_{LS} = \frac{N}{T_{vd}} \tag{1}$$

where Q_{LS}—the real capacity of a milking parlor, goat min^{-1}; N—the number of lactating goats on the farm, goat; T_{vd}—the duration of one milking, min.

An important parameter taken into consideration is represented by the milking time. The advantage of reducing the duration of milking operation enables goats to have the opportunity to take feed and rest, to go grazing, and so on. Since goats are milked in groups and the provided data obtained by measurement are determined by milked groups, the time T_{vd} can be determined by Equation (2) as the total time spent by all groups of goats in the milking parlor.

$$T_{vd} = \sum_{i=0}^{n} T_{d1g} \tag{2}$$

where T_{d1g}—total duration time of a single milking, min; n—number of goat groups.

The total duration time of single milking of a group of goats in the milking parlor T_{d1g} as the sum of partial times of individual operations and movements is determined by Equation (3).

$$T_{d1g} = t_{z1} + t_{z2} + t_{pr} + t_n + t_d + t_s + t_o + t_u \tag{3}$$

where T_{d1g}—duration time of a single milking of one goat group, min; t_{z1}—the time of moving a group of goats to the milking parlor, min; t_{z2}—the time of arrangement of goats on the milking stalls, min; t_{pr}—the time of preparation for milking, min; t_n—the time of

placement of teat cups, min; t_d—the time of one milking, min; t_s—the time of removing the milking cluster, min; t_o—the time of treatment (disinfection of teats) after milking, min; t_u—the time a group of goats leaves the milking parlor, min.

With regard to a human working process and working operations, the total time of single milking, preparation, and subsequent work included is determined by Equation (4).

$$T_{c1d} = T_{vd} + T_p + T_c + T_L \quad (4)$$

where T_{c1d}—total duration time of a single milking including preparatory operations and finishing work after milking, min; T_p—the time of preparatory work before milking, min; T_c—the time of finishing and cleaning work after milking, min; T_a—accessory times, time dedicated to other activities during milking (emptying the bucket, manual distribution of concentrate, recalling goats from the pasture, etc.), min.

When period T_{c1d} is short enough, then there is enough time for workers (milkers) to carry out the other activities (feed preparation, cleaning, control of animals, etc.). Therefore, time should be a criterion for optimization and the selection of a suitable milking parlor for the farm.

The second decisive criterion should be the economic criteria. It is necessary to compare the specific data, which are, in this case, the final specific direct costs of a milking parlor per goat and year ${}^{u}C_{MP}$, calculated according to Equation (5) as a sum of specific labor costs of milking per goat and year ${}^{u}C_W$, specific costs of the milking equipment per goat and year ${}^{u}C_P$, including construction, and specific costs ${}^{u}C_S$ of supplies, including the water, electricity, disinfectants, etc., per one goat and year.

$${}^{u}C_{MP} = {}^{u}C_W + {}^{u}C_P + {}^{u}C_S \quad (5)$$

where ${}^{u}C_{MP}$—the final specific direct costs of the milking parlor, EUR goat^{-1} year^{-1}; ${}^{u}C_W$—the specific labor costs per goat and year, EUR goat^{-1} year^{-1}; ${}^{u}C_P$—the specific costs of the milking equipment, EUR goat^{-1} year^{-1}; ${}^{u}C_S$—the specific costs of consumed supplies, EUR goat^{-1} year^{-1}.

Specific labor costs ${}^{u}C_W$ are based on labor requirements per goat per year T_r (h goat^{-1} year^{-1}) obtained by using Equation (6) and an average hourly wage of the milker.

$$T_r = \frac{365 \cdot i \cdot T_F}{60 \cdot N} \quad (6)$$

where T_r—the labor requirement for milking per goat per year, h goat^{-1} year^{-1}; T_F—the time required and paid by the farmer to milk all lactating goats N, min; i—the number of milkings per day, day^{-1}.

Specific costs of the equipment ${}^{u}C_P$ are evaluated as specific data of total operating costs of the machine per single goat. Therefore, they include the amortization of machinery, which is the purchase price of the machine expressed by the percentage of machine amortization, further amortization of construction, which includes construction costs and percentage of building amortization, and the cost of servicing, maintenance, and repairs, which are usually expressed as a percentage of planned acquisition costs.

Specific costs of supplies ${}^{u}C_S$ are determined as a sum of all necessary operating materials and energy costs. The consumption of electricity is proportional to the power inputs of motors and all electrical appliances during their operation, water, disinfection, etc. All are recomputed per goat and year (EUR goat^{-1} year^{-1}).

The model makes it possible to calculate the waste of time T_L, determined by measurement and calculation of the time T_{c1d} and compared with the time T_F given by the farmer (from which the actual wage of the milker is calculated), according to Equation (7). The average hourly wage is considered to be, in the case of an internal worker (usually a family member from the farm), EUR 7.43 hour^{-1}, or for an external employee, EUR 11.06 hour^{-1}.

This makes it possible to calculate from this time waste T_L the specific financial loss ${}^{u}C_L$ derived in Equation (8).

$$T_L = (T_F - T_{c1d}) \cdot n_{ds} \quad (7)$$

where T_L—the time waste for one milking, min; n_{ds}—the number of milkers.

$${}^{u}C_L = \frac{365 \cdot i \cdot T_w \cdot s_h}{60 \cdot N} \quad (8)$$

where ${}^{u}C_L$—the specific financial loss, EUR goat^{-1} year^{-1}; s_d—the wage paid per hour, EUR hour^{-1}.

2.2. Description of the Farms and Milking Parlors

The described model was employed to evaluate the process in typical goat farms for the current situation in the Italian primary sector. All data (e.g., construction and equipment costs, costs of supplies, labor costs, etc.) used for the calculation were collected from nine farms focused on breeding goats for milk production. The farms breed Italian Camosciata delle Alpi and Italian Saanen dairy goat, very common in the Friuli-Venezia Giulia region (Northeast Italy). The selected farms were very diversified both from the point of view of the location, the average size (number of lactating goats), and the typology of the milking system chosen. Five farms (A, I, F, B, G) have a milking pipeline and milk their animals (respectively, 82, 56, 229, 120, and 41 lactating goats) in a one parallel stall milking room or a milking stand located in the stall. Farm E has two sides of parallel stalls in a milking room and milks 110 lactating goats with a pipeline system. Two farms (D and H) milk their goats with bucket milking system (respectively, 48 and 62 lactating goats). Farm B milks some of the goats (50) with a milking cart (named farm C), since they are in another building of the farm. Farm J also milks its 52 lactating goats with a cart milking machine.

3. Results and Discussion

3.1. Characteristics of the Farms and Milking Parlors

Basic capacity data of farms and real technical parameters of farms and milking parlors are presented in Table 1.

Table 1. Analyzed dairy goats' farms with milking parlors.

Parameter	Nomenclature	Farm A	Farm B	Farm C
Number of goats in lactation	N	84	120	50
Milk production (kg·goat^{-1}·year^{-1})		1000	700	700
Type of milking parlor	-	Side-by-side milking pipeline	Side-by-side milking pipeline	Side-by-side milking cart
Number of milking stalls	m	12	24	8
Number of milking clusters	m_c	6	8	2
Number of milking groups	n_g	7	5	7
Number of goats in one group	N_g	12	24	8
Year of installation	-	2011	2000	2021
Automatic cluster remover	-	Yes	No	No
Costs of milking parlor equipment (EUR)	-	20,000	25,823	1300
Number of milkers (internal or external)	n_d	1 external or 2	1 external	1 internal

Table 1. *Cont*.

Parameter	Nomenclature	Farm D	Farm E	Farm F
Number of goats in lactation	N	48	110	229
Milk production ($kg \cdot goat^{-1} \cdot year^{-1}$)		900	950	830
Type of milking parlor	-	Side-by-side bucket milking system	Side-by-side milking pipeline	Side-by-side milking pipeline
Number of milking stalls	m	8	12 + 12	24
Number of milking clusters	m_c	4	12	12
Number of milking groups	n_g	6	10	10
Number of goats in one group	N_g	8	12	24
Year of installation	-	2019	2019	2016
Automatic cluster remover	-	No	Yes	Yes
Costs of milking parlor equipment (EUR)	-	1638	65,000	55,000
Number of milkers (internal or external)	n_d	1 internal	2 externals	1 or 2 internal

Parameter	Nomenclature	Farm G	Farm H	Farm I	Farm J
Number of goats in lactation	N	41	62	56	52
Milk production ($kg \cdot goat^{-1} \cdot year^{-1}$)		700	805	583	940
Type of milking parlor	-	Side-by-side milking pipeline	Side-by-side bucket milking system	Side-by-side milking pipeline	Side-by-side milking cart
Number of milking stalls	m	15	16	10	/
Number of milking clusters	m_c	4	2	4	2
Number of milking groups	n_g	4	4	6	8
Number of goats in one group	N_g	10	16	10	6
Year of installation	-	1991	Data non received	2019	2017
Automatic cluster remover	-	No	No	No	No
Costs of milking parlor equipment (EUR)	-	Data not received	1220	1300	1800
Number of milkers (internal or external)	n_d	1 external	1 internal	1 or 2 internal	1 internal

Table 2. Average values of partial times of the time schedule for all groups.

Partial Time	t_{z1} (min)	t_{z2} (min)	t_{pr} (min)	t_n (min)
Mean	0.08	0.43	0.83	1.23
SD	0.09	0.29	0.51	0.93
Partial Time	t_d **(min)**	t_s **(min)**	t_o **(min)**	t_u **(min)**
Mean	6.38	0.48	0.50	0.49
SD	2.94	0.41	0.34	0.47

Notes: t_{z1}—time of moving a group of goats to the milking parlor (min); t_{z2}—time of arrangement of goats on the milking stalls (min); t_{pr}—time of preparation for milking (min); t_n—time of placement of teat cups (min); t_d—time of one milking (min); t_s—time of removing the milking cluster (min); t_o—time of treatment (disinfection of teats) after milking (min); t_u—the time a group of goats leaves milking parlor (min).

Table 3. The real time of all groups of goats spent in a milking parlor T_{vd} (min) and total time of a single milking T_{c1d} (min).

Parameter	Nomenclature	Farm A	Farm B	Farm C	Farm D	Farm E
The time of all groups spent in a milking parlor (min)	T_{vd}	84.22	81.82	46.6	57.2	54.13
Real time of a single milking (min)	T_{c1d}	109.32	140.3	80.65	106.8	89.13
Parameter	**Nomenclature**	**Farm F**	**Farm G**	**Farm H**	**Farm I**	**Farm J**
The time of all groups spent in a milking parlor (min)	T_{vd}	97.97	48.83	68.83	40.33	71.43
Real time of a single milking (min)	T_{c1d}	122.97	66.42	115.83	68.43	111.43

Notes: T_{vd} (min) and total time of a single milking T_{c1d} (min).

Table 4. The real capacity of milking parlors.

Parameter	Nomenclature	Farm A	Farm B	Farm C	Farm D	Farm E
The capacity of a milking parlor (goat min^{-1})	Q_{LS} *	1.00	1.47	1.07	0.84	2.03
Parameter	**Nomenclature**	**Farm F**	**Farm G**	**Farm H**	**Farm I**	**Farm J**
The capacity of a milking parlor (goat min^{-1})	Q_{LS} *	2.34	0.84	0.93	1.39	0.73

* Q_{LS}—capacity of milking parlor (goat min^{-1}).

Table 5. The daily waste of time T_L (min) and the specific financial losses related to labor ${}^{u}C_L$ (EUR goat^{-1} year^{-1}) in the goat farms.

Parameter	Nomenclature	Farm A	Farm B	Farm C	Farm D	Farm E	Farm F
Waste of time *	T_L	14.20	55.47	54.67	9.20	20.00	0.00
Specific financial losses *	${}^{u}C_L$	14.3	31.1	49.4	8.7	24.5	0.0
Parameter	**Nomenclature**	**Farm G**		**Farm H**		**Farm I**	**Farm J**
Waste of time *	T_L	44.67		80.87		34.37	34.37
Specific financial losses *	${}^{u}C_L$	73.3		59.0		27.7	30.0

* For daily waste of time T_L (min) and the specific financial losses related to labor ${}^{u}C_L$ (EUR goat^{-1} year^{-1}), it was hypothesized an addition of clusters, where the ratio of clusters to milking stalls was not considered adequate.

3.2. Milking Times

The evaluation of current milking conditions enabled us to compare all farms and milking parlors. The average values of the partial times calculated based on the analysis of the time schedule for all groups on the individual farms are given in Table 2. All partial times summarized together create average time T_{d1g} (min) of one group of goats spent in the milking parlor.

The sum time of all groups of goats spent in a milking parlor T_{vd} (min) and the total time of one milking T_{c1d} (min), including the preparation of the milking parlor before milking T_p (min) and washing and disinfection after milking T_c (min), are summarized in Table 3.

The summarized results of measurements and calculations at the farms A–J are depicted in Figures 1–4. The diagram presented in Figure 1 is based on the detailed analyses of real time schedules of milking operations in all evaluated goat farms.

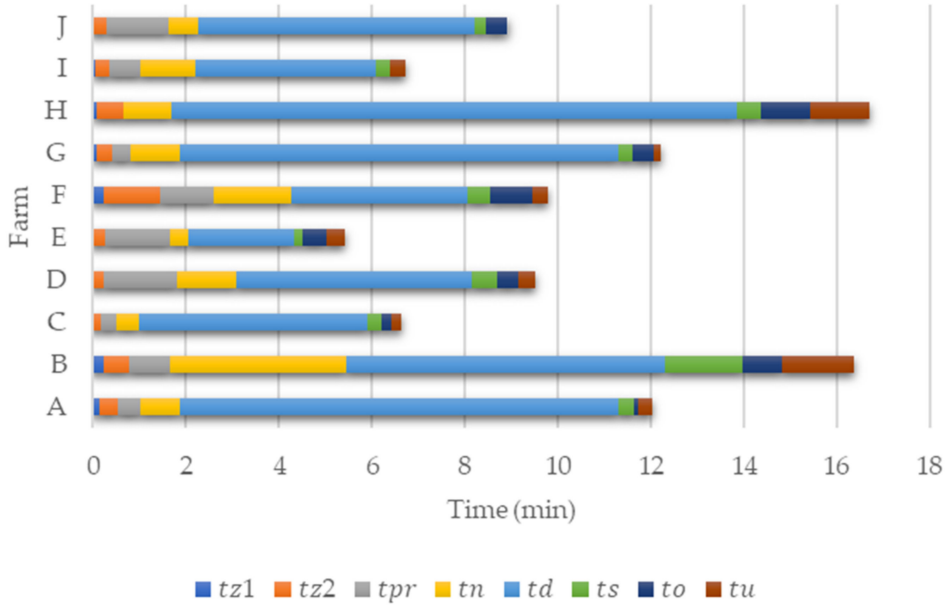

Figure 1. Average time spent in the milking parlor for a group of goats T_{d1g} (min), as schedules of milking operations at all analyzed goat farms (t_{z1}—the time of moving a group of goats to the milking parlor (min); t_{z2}—the time of arrangement of goats on the milking stalls (min); t_{pr}—the time of preparation for milking (min); t_n—the time of placement of teat cups (min); t_d—the time of one milking (min); t_s—the time of removing the milking cluster (min); t_o—the time of treatment (disinfection of teats) after milking (min); t_u—the time a group of goats leaves the milking parlor (min).

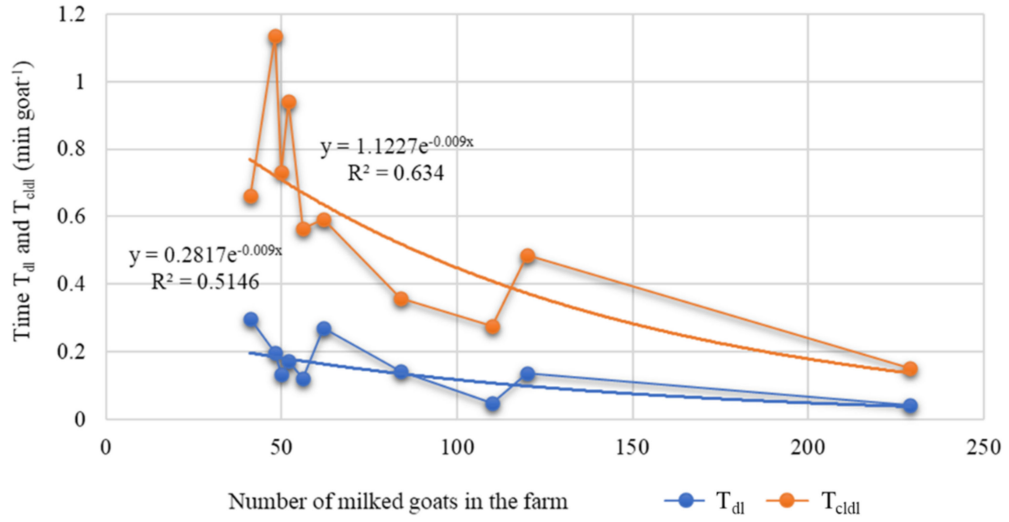

Figure 2. Average specific time T_{d1} (min) of stay of goats group in a milking parlor and average specific total time T_{c1d1} (min) of a single milking operation at analyzed goat farms, calculated per one goat.

The comparison of duration of average specific stay time T_{d1} (min) of goats group in a milking parlor and average total time T_{cd1} of a single milking operation calculated per one goat and the number of milked goats N (in lactation) in the farms are presented in Figure 2.

The current real time of a single milking T_{c1d}, which consists of the time of all groups of goats spent in a milking parlor T_{vd} and preparatory work before milking T_p and the time of finishing and cleaning work after milking T_c, is presented in Figure 3.

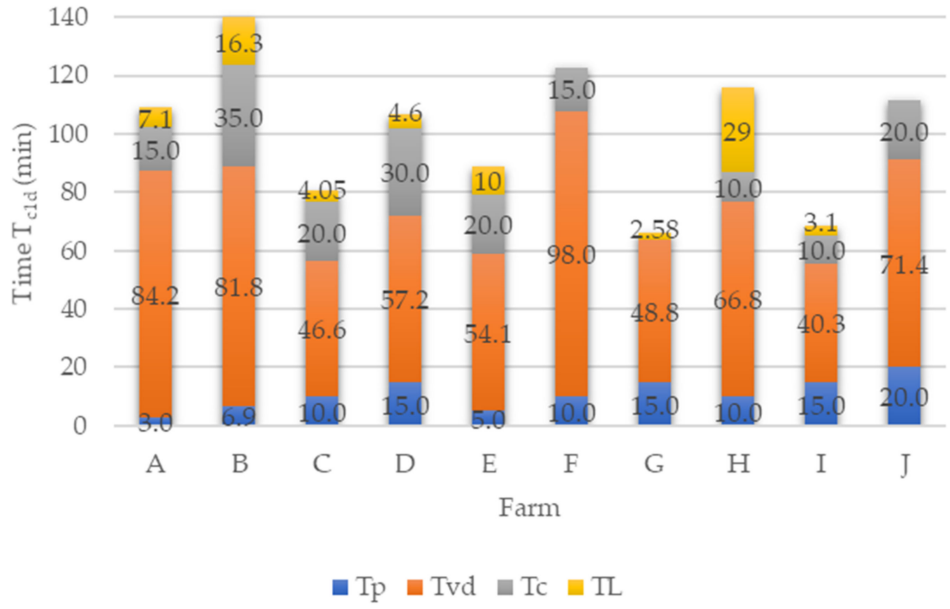

Figure 3. Current real time of a single milking T_{c1d} (min) at all analyzed dairy farms (T_p—the time of preparatory work before milking, min; T_{vd}—the real time of all groups of goats spent in a milking parlor min; T_c—the time of finishing and cleaning work after milking, min; T_L—accessory times, min).

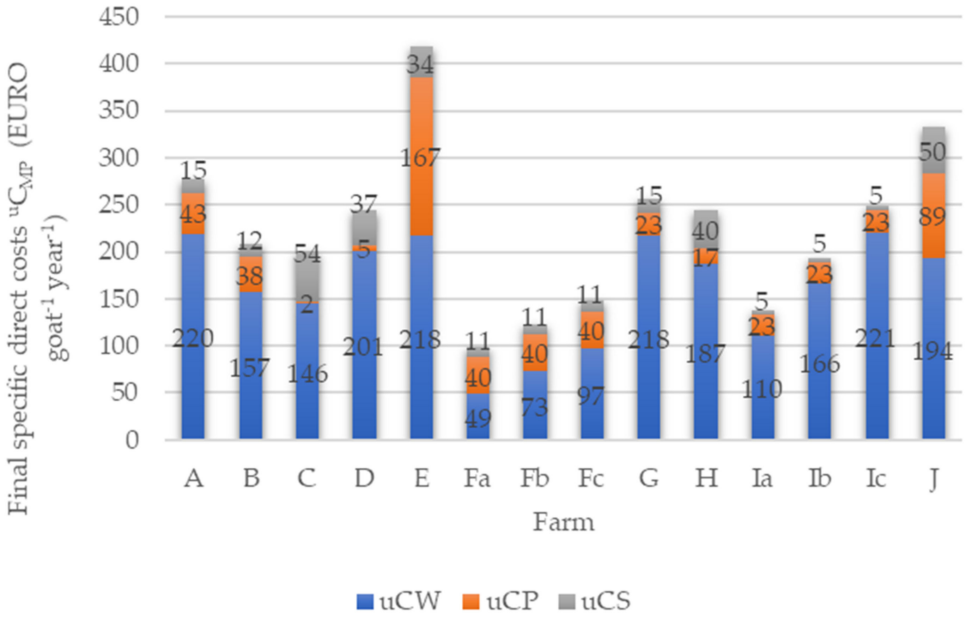

Figure 4. Final specific direct costs of milking $^{u}C_{MP}$ (EUR goat^{-1} year^{-1}) in the milking parlors in the current situation at all goat farms ($^{u}C_W$—specific labor costs (EUR goat^{-1} year^{-1}); $^{u}C_P$—specific costs of the milking equipment (EUR goat^{-1} year^{-1}); $^{u}C_S$—specific costs of consumed supplies (EUR goat^{-1} year^{-1}).

3.3. Capacity of the Milking Parlors

The real capacity of a milking parlor, based on the measurement of partial time schedule and calculated according to Equation (1), is presented in Table 4, while, daily waste times T_L and consequent specific financial losses $^{U}C_L$, calculated according to Equations (7) and (8), are presented in Table 5.

The analysis of the measured and calculated parameters shows that the time of one milking t_d has the greatest influence on the length of average time spent in the milking

parlor for a group of goats T_{d1g}. The shortest time of one milking t_d (2.26 min) is on farm E, where other partial times forming time spent in the milking parlor are short, therefore this time T_{d1g} is also the shortest (5.80 min) of all examined farms. This is reflected in a shortfinal time for all milked groups T_{vd} (54.13 min), and in a short real time of a single milking T_{cld} (89.13 min).

The opposite is the situation on farm H (62 goats), which has a milk production of 805 kg goat^{-1} year^{-1}. The time of one milking t_d (12.7 min) and, thus, the time T_{d1g} (16.71 min) are unusually long. The longer milking time is due to the inadequate number of teats, which prolongs the time of one milking. The time of leading a group of goats from the milking parlor is also high; on average it takes 1.26 min, thus leading to a lengthening of the time.

The smallest number of milked goats in lactation N are on farm D (48 goats) and farm G (41 goats). The farms E and F have a relatively high real capacity of milking parlors Q_{LS} (respectively, of 2.03 and 2.35 goat min^{-1}) compared to others. This has a positive effect on the operation of the farm from the point of view of the organization and it also significantly reduces labor costs. Farmers have sufficient time for other activities and goats have a longer time of quiet period for rest.

However, milk production on these farms is only average on both farms B + C and G (700 kg goat^{-1} year^{-1}) and it is in the interest of many farmers to increase farm capacity and increase milk yield, thus achieving higher total milk production. The best milk yield (1000 kg goat^{-1} year^{-1}) is achieved on farm A (84 goats). There is also a relatively short time T_{vd} on this farm in which the goats spend in the milking parlor (84.22 min), but 1.5 milkers work here.

There is a significant unevenness on the farms in terms of time to prepare the T_p milking parlor, which is the shortest on farm A (3 min) and the longest on farm J (20 min), and in terms of time for final work activities after milking T_c is the shortest on farms H and I (10 min) and the longest on farms B (35 min) and D (30 min), which is reflected in the real time of single milking T_{c1d} (Table 3 and Figure 3). For farm G, the data regarding the time for final work activities after milking were not acquired.

3.4. Milking Specific Costs

In addition to operating conditions, milking time also has a great impact on the economy of the milking parlor. As can be seen from the results of the calculation of specific costs (Figure 4), for all farms, the largest share has specific labor costs ${}^{u}C_W$. Compared to the operation of milking parlors for dairy cows, the specific costs of the milking parlor ${}^{u}C_P$ are smaller, and the specific costs of consumed supplies ${}^{u}C_S$ are also very small. According to Chiumenti et al. [2], for dairy cows, the specific costs of the milking parlor ${}^{u}C_P$ represent the main part of the final specific direct costs ${}^{u}C_{MP}$. In addition, Kic [16], in his work, highlighted the greater influence of the specific costs of the milking equipment for dairy cows on final specific direct costs.

The size of the groups for milking and their number are reflected in the organization of the entire milking process, and thus in the resulting time needed for milking. Regarding the final specific direct costs of milking ${}^{u}C_{MP}$, the best economic conditions are achieved at the biggest farm, F (229 goats and average milk production 830 kg goat^{-1} year^{-1}). This farm has a relatively recent milking parlor with 24 milking stalls, 12 milking clusters, and automatic cluster remover. The process of milking is organized in 10 groups of goats coming together in the milking parlor. There are alternatively working 1 or 2 milkers from the farmer's family.

The calculation of economic criteria for the Farm F is provided for three variants of milking (F_a, F_b, and F_c) with 1, 1.5, and 2 milkers, which enables a comparison of the results. The duration time of the milking process T_{c1d} is the same in all cases (122.97 min), but specific labor costs ${}^{u}C_w$ are growing passing from 1 to 1.5 and to 2 workers employed. The same calculation of economic criteria was then also applied to farm I, which, similar to farm F, carries out milking operations by employing 1 or 2 milkers from the farmer's

family. From Figure 4 it can be seen that as the number of milkers employed increases, this respectively increases the specific labor costs. The costs are even higher if the milking operation is carried out by an external worker (for example, in the farms A, B, E, and G).

The highest specific costs of the milking parlor ${}^{u}C_P$ 167 EUR goat^{-1} year^{-1} are calculated for farm E, with a herd of 110 lactating goats, and equipped with the most expensive parallel milking parlor with 12 + 12 stalls and swing-over milking unit.

4. Conclusions

The technology of mechanical milking is continuously evolving, and farmers and technicians must keep themselves constantly informed. The dissemination of knowledge among farmers and technicians is fundamental for proper management, optimization, and correct understanding of the specific performances of different equipment and methods.

The dairy goat sector shows a substantial increase in the number of heads per farm; this entails the need to have specific milking systems, opening new markets to manufacturing companies and favoring technological evolution.

Choosing the right milking system must be meticulous, as milking is the key stage in which profit is generated. Despite the differences between the farms evaluated, in general, it was seen that the choices made by farmers for milking systems were not always optimal. In many cases, milking systems were not correctly sized according to the number of lactating goats.

The data analysis highlighted that side-by-side with pipeline milking systems were more efficient in reducing milking time compared to bucket and cart systems; even if these systems require a greater initial investment, their diffusion in the goat sector is constantly increasing.

In choosing the type of system it is important to consider the economic aspect, which certainly does not represent a secondary aspect to the efficiency of the system applied to the specific business situation. In some cases, the purchase of an unsuitable system does not improve or even extend milking time, compromising the effectiveness of the intervention. Therefore, to reduce costs it is important to know the exact time needed for milking with different systems.

The following conclusions can be drawn from the research performed on the farms and from the results of the model calculation:

- Milking systems have to be suitable for the number of lactating goats, since the high capacity of a system reduces the final costs. The addition of milking clusters to existing systems or the radical change of the milking system, adopting the pipeline system, would result in significant savings of time and manual labor;
- The proposed mathematical model includes the main technical parameters, indicators of labor productivity, and economic criteria;
- Neglect or promotion of only one of the mentioned criteria may lead to an uneconomic investment or impaired operation of a farm;
- The evaluation of existing milking parlors can help to improve the milking process and operations from the point of view of either technical improvement or improved activity of milkers;
- The preliminary calculations performed as the initial basis of the project allow an analysis of positive and negative aspects of various milking parlors solutions.

This study demonstrated that increasing the capacity of dairy goat farms enables the reduction of the final specific direct costs for milking. The energy consumption related to goat milk production chain, and in particular to milking systems, and the opportunity of using sustainable and self-produced energy sources in the goat farm (i.e., solar energy or biogas from animal manure) represent aspects that should be faced by future research, for further enhancing this sector.

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