AgriEngineering

Technical Note

Milking Machine Settings and Liner Design Are Important to Improve Milking Efficiency and Lactating Animal Welfare—Technical Note

Shehadeh Kaskous [1,*] and Michael W. Pfaffl [2]

[1] Department of Research and Development, Siliconform, Schelmengriesstrasse 1, 86842 Türkheim, Germany
[2] Department of Animal Physiology and Immunology, TUM School of Life Sciences, Technical University of Munich, Weihenstephaner Berg 3, 85354 Freising, Germany; michael.pfaffl@tum.de
* Correspondence: skaskous@siliconform.com

Abstract: The purpose of milking machines is to harvest milk at optimal quality and speed, while maintaining animal comfort and teat defense mechanisms against invading mastitis pathogens. Therefore, the milking machine is a very important piece of equipment on dairy farms to maintain a long healthy lactation by following the physiological conditions of the udder. The mechanical forces during long-term machine milking processes lead to changes in the teat tissue. This effect is related to the degree of adaptation of the milking machines to the physiological requirements of the individual udder anatomy and the physiological conditions of the lactating animals. If both, milking machine settings and liner design are not suitable for all teats and animals on the farm, some animals will not be fully milked, the teat condition will deteriorate over time and in the end, they may suffer from mastitis. Therefore, maintaining healthy udders and teats during milking is a central key component of an effective milking machine to produce good milk yield with higher quality by preventing mastitis and maintaining animal health and welfare. On large and thick teats, conventional liners often fit too tight, causing a massive mechanical stress load on the tissue. On small teats, however, they often do not adhere sufficiently close to the teat which can cause a considerable air admission and hence liner slips. The new liners, "Stimulor® StressLess" (Siliconform, Türkheim, Germany), have a wave-like lip construction and adapt well to the different teat sizes in a herd, thus ensuring consistent milking of lactating animals. A proper milking machine accommodates all teat sizes and forms, has a low vacuum to effectively open the teat and to stimulate physiological milk release and letdown. In addition, the right pulsation rate will maintain a stable vacuum on the teat area during milking. In conclusion, an ideal milking machine adapts to the morphological, anatomical, and physiological characteristics of the udder and teats of the lactating animals and it should achieve a physiologically ideal milking process that meets high animal welfare standards and increases milk production with a high quality standard.

Keywords: lactating animals; liner; milking machine; Stimulor® StressLess; teat cup

Citation: Kaskous, S.; Pfaffl, M.W. Milking Machine Settings and Liner Design Are Important to Improve Milking Efficiency and Lactating Animal Welfare—Technical Note. *AgriEngineering* **2023**, *5*, 1314–1326. https://doi.org/10.3390/agriengineering5030083

Academic Editors: Muhammad Sultan, Yuguang Zhou, Redmond R. Shamshiri and Muhammad Imran

Received: 14 June 2023
Revised: 21 July 2023
Accepted: 26 July 2023
Published: 28 July 2023

1. Introduction

An increase in milk yield through increased milk synthesis, milk secretion and a long and stable persistence (a slower drop in yield over the course of the lactation) is possible if the healthy udder is emptied frequently and completely. Bruckmaier and Blum [1] have emphasized that optimal machine milking removes the stored milk from the udder cistern quickly and completely while maintaining udder health with the aim of harvesting high milk yield, maintaining animal health, and achieving low milking costs. Several researchers have also shown that milking machine settings such as pulsation frequency and ratio, vacuum level and automatic teat cup removal have a major impact on milk yield, milking time, and overall udder health [2–7]. However, the milking machine is known to affect the milk produced and its quantity and quality in lactating animals [5,8–10].

An unsuitable milking machine is cited as the cause of milking that is too slow or too rough, not physiological, and therefore incomplete. Crooked teat cups, no proper pulsator, higher vacuum and wrongly dimensioned teat liners are factors resulting in an unsuitable milking process for the lactating animals. The reason for this may be low milk yield, longer milking times, and impaired udder health. Maintaining udder health during milking is very important to achieve high yield with good milk quality. It is well known that the mechanical forces of an improperly used machine milking results in poor teat tissue changes [11] and allows pathogenic bacteria to penetrate the udder [12], particularly via the skin of the teat end, which will increase the risk of new mastitis infections and thereafter increase somatic cell count (SCC) in the milk [13–15].

Moreover, it should be noted that insufficient pre-stimulation can lead to poor milking performance, especially in cows, camels, and buffalo, which have small udder cisterns and large amount of alveolar milk [1,16–19]. A new study has shown that efficient machine milking requires an optimal interaction between the alveolar milk ejection in the udder induced by hormonal posterior hypophyseal oxytocin release, smooth muscle contraction of the alveolar myoepithelial cells and thereafter the milk removal by the milking machine [19]. The timely onset of this milk ejection is particularly important for animals and species with low levels of cistern milk. Most milk in sheep and goats can be obtained before ejection, because the proportion of cistern milk is significantly high. The cistern milk can account for up to 70% of the stored milk (depending on the breed) [20]. However, having an insufficient pre-stimulation in cattle results in delayed oxytocin release and milk ejection, and a separate removal of the cisternal milk before milk ejection is required. This causes the well-known milk flow pattern in bovines [17]. Therefore, mechanical udder preparation must be ensured in order to trigger the physiological milk ejection at the right moment [21]. In addition, it was observed that the average milk flow was higher when milk was removed within the first two minutes of milking, and the duration of incline and time until peak milk flow were shorter with pre-stimulation than without pre-stimulation [19]. Sandrucci et al. [22], reported that a proper udder preparation, including teat fore-stripping and pre-dipping resulted in better milking performances compared to a poor preparation. This results in a higher milk yield per milking, shorter milking time, lower bimodality, lower SCC in the milk, and better animal welfare.

Many milking machines offer modern technology at a high level. However, the milking system chosen is not always suitable for all animals in the herd, since the physiological control mechanisms and oxytocin release in animals are individual and cannot be changed by humans. The milking routine and technology must be adapted to the animal anatomy and physiology in order to achieve optimal milk removal [23]. Gasparik et al., [5] reported that optimal values for milking machine settings to better adapt to animal physiology were still discussed among scientists. For this reason, many farms suffer with their own milking machines because the demands of the lactating animals are not yet met. This means that the milking machine must act in a natural and gentle way similar to suckling the calf, and must not be uncomfortable or painful for the animals. Observations on suckling calves showed that the calf can drink all the milk while the udder remained healthy [23]. Interestingly, it was reported that Siliconform's milking philosophy is to increase the milk yield, improve the quality, protect animal welfare, and reduce production costs. Therefore, the milking machines "MultiLactor" for cows and "StimuLactor" for camels were developed [24]. Field studies have shown that cows on the farm remained healthy with a MultiLactor quarter-individual milking system throughout the study period. The reason for this lies in the use of the right milking machine, milking program, and optimally fitting liners, e.g., suitable teat cups with an air inlet valve (also known as Bio-Milker; Siliconform), suitable silicone liner, low vacuum level, correct pulsation rate and pulsation ratio [10,25].

Furthermore, when the lactating animals are milked, the teat cup liner is the immediate interface between the technical aggregate of the milking machine and the highly sensitive organ, the teat skin. Therefore, the liner and milking machine settings have a significant influence on the duration of milk removal, the degree of udder emptying, the maintenance of udder health and finally, on the overall quality of the raw milk [14,15,24,26–28]. In the following, the importance of the milking machine settings and liner design for optimal milking performance and welfare of the lactating animals are summarized and discussed.

2. Influence of Milking Machine Settings on Milk Removal

The ideal milking system meets the physiological needs of lactating animals to increase milk yield, achieve better milk quality and maintain healthy udders. Therefore, the settings of the milking machine are very critical to lactating animals [5,29]. Individual quarter pulsation milking systems may prevent overmilking and improve teat-end condition [10,25,30]. Besides the liner, there are three operating parameters that regulate mechanical milking: vacuum level, pulsation rate and pulsation ratios. The milking system needs to provide stable vacuum, adequate pulsation, and gentle milking action. Inside the teat liner there is a continuous negative pressure (vacuum) between 36 and 50 kPa, which causes the teat cup to adhere to the teat, overcoming the teat canal resistance and transporting the milk that has escaped during the suction phase. Therefore, the vacuum directly "under the teat" is subject to dynamic changes due to cyclic liner movement and stop-and-flow of the milk [27]. However, the pressure in the pulsation chamber of the teat cup alternates (controlled by the pulsator) between operating vacuum (suction phase) and atmospheric pressure (relief phase) [31]. Reinemann and Mein, ref. [32] reported that the right choice of a liner, vacuum level and pulsation settings are essential for balanced milking that needs to be fast, smooth, and complete. The mechanical stress on the teat is always present and is essentially caused by the teat liner shaft [21]. This mechanical stress becomes harmful during the relief phase, if a high differential pressure quickly builds up between the teat end vacuum and inside the pulsation chamber and the liner shaft compresses the teats at high speed [5]. This is almost always the case during blind milking and at low milk flow rates at the end of the milking period. The resulting differential pressure is greater, the higher the milking vacuum was set. For example, if you milk with a vacuum of more than 40 kPa, the teats of the cows are unnecessarily stressed. In nature, the teats must only withstand the relatively gentle massage pressure of the suckling calf's tongue. On the other hand, teat liners are often significantly harder, less flexible and put more stress on the teat tips. However, this is exactly where the sphincter muscle and the teat canal are anatomically located, which are both supposed to take over the essential infection barrier function.

2.1. Influence of the Vacuum Level in the Milking Machine on Milk Removal

Obviously, the vacuum from the milking machine opens the teat canal and milk flows out during suction phase, but blood and lymph from the teat wall are also drawn to the end of the teat. The collapsing liner exerts a mechanical force on the end of the teat during the relief phase, closing the teat canal and transporting blood and lymph back to the udder. However, the mechanical stress on the teats during mechanical milking, both through teat stretching due to the high vacuum in phases when the liner is open and through compression due to the closed liner, leads to a temporary occlusion of the blood vessels in the teat wall [11]. Further, vacuum and pulsation ratio are important operating parameters that affect milking performance by milking machine [33]. The results also clearly demonstrated the importance of increased vacuum in the mouthpiece chamber for teat end congestion and the consequent reduction in cross-sectional area [34].

It has been observed that teat end hyperkeratosis increases with increasing liner pressure of the milking machine, and this furthermore depends on the length of the teat cup and the type of milking situation [35]. When the liner closes in the relief phase, a vacuum overpressure from the milking machine is exerted negatively on the teat. Vacuum levels and milking machine settings are known to affect milking behavior and teat tissue condition [36]. It has been found that high vacuum (50 kPa) in the milking machine compared to lower vacuum (42 kPa) can lead to teat tissue damage, milk duct damage and hyperkeratosis [37]. New research emphasized that the frequency of bimodalities with both pre-stimulation and without pre-stimulation was higher at high vacuum level than at low vacuum level [19]. The use of high milking vacuum for camels could lead to udder health problems reflected by a high somatic cell count in the produced milk and a negative impact on the health status of the teats [18]. A positive relationship between increasing working vacuum and somatic cell counts in the milk has been found in buffalo [38] and other dairy species [14,39–41]. Normally, the vacuum pump creates a vacuum for the whole milking system (vacuum line, milk line and all connected tubes and equipment) and determines the vacuum in the claw and pulsator chambers. The milking vacuum depends on many factors, e.g., the vacuum required to pump the milk (high line), the length and diameter of the milk tube and the number and type of devices integrated in the system [42,43]. Furthermore, the vacuum in the milking machine is the main force required to keep the liner on the teats during milking. An interesting aspect is that the lack of milk flow during milking at the beginning and end of the milking process causes increased vacuum forces on the teats, which can lead to greater teat damage [43]. Conversely, when the milk flow is high during the plateau phase, the loss of vacuum is particularly high compared to the beginning or end of milking when the milk flow is low [36,41]. It is noteworthy that a drop in claw vacuum during milking can reduce milking efficiency by reducing milk removal efficiency. Several lines of evidence indicate that modern milking machines with Bio-Milker liners (Siliconform) clearly show, during the suction phase with low milk line, that the vacuum in the inner chamber remains stable or slightly higher than in the pulsation chamber [7].

Figure 1 shows the vacuum conditions in the Bio-Milker (Siliconform) teat cup. With this teat cup, the pressure on the teats is not too high during the relief phase. As can be seen from the diagram, the vacuum in the inner chamber during the relief phase is low compared to a normal teat cup. As a result, the blood flows easily and no congestion is seen. Bio-Milker (Siliconform) teat cups are known to have a stable vacuum in the teat area and consequently minimized vacuum loss, had no engorgement and drastically reduced the risk of infection [23]. Normal milking machines without the Bio-Milker teat cup show different results, namely: in the absence of milk flow, the vacuum in the inner chamber is similar to the full system vacuum level, whereas it drops as soon as milk is available and is transported in the milk tubes [36]. However, it should be noted that in high-line milking systems, the vacuum level in all milking machines decreases during the period of high milk flow rate [7,44]. Therefore, a vacuum drop in the inner chamber during machine milking can affect milking performance [41] and increase the probability of liner slips [43].

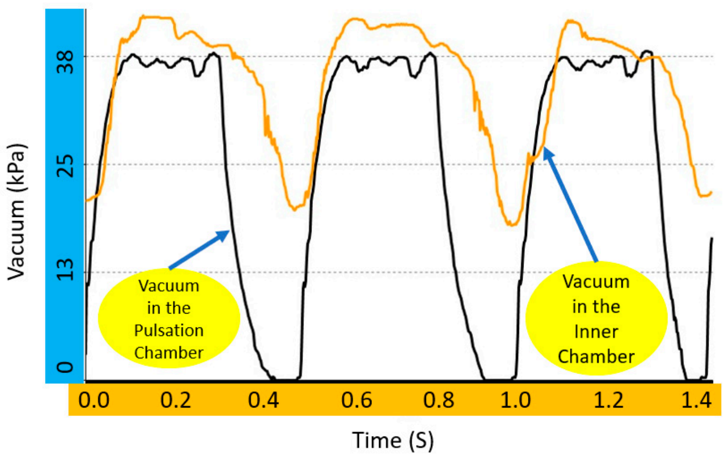

Figure 1. Cyclical vacuum fluctuations in the pulsation and inner chambers of the teat cup (Bio-Milker teat cup liners, Siliconform) during milking in the sheep milking machine with the following settings: vacuum level 38 kPa, pulsation rate 120 cycles/min and pulsation ratio 60:40 [7].

2.2. *Influence of Pulsation Rate and Pulsation Ratios in the Milking Machine on Milk Removal*

A pulsator is a device for generating cyclic pressure changes in the pulse system of a milking machine. As a switch, it alternately connects the impulse chamber of the teat cup with the vacuum supply of the milking system or with atmospheric air. The periodically changing pressure conditions in the two-chamber teat cup control the movement of the teat liner and thus the change between milk flow (suction phase, b-phase) and circulatory relief of the teat by pressing the teat liner (relief phase, d-phase) [5,42,45] (Figure 2).

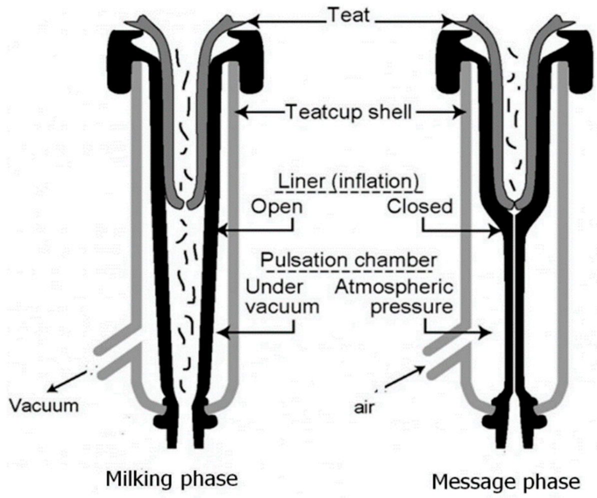

Figure 2. Suction phase (milking phase) and relief phase (massage phase) in mechanical milk removal according to Krömker [31] with some changes.

The main purpose of the pulsation is to limit the formation of congestion and oedema in the teat tissue during machine milking [46]. However, the function of the pulsation in the teat cup is to squeeze the end of the liner, which supports the return flow of blood and lymph through the veins and lymphatics during milking [47]. Thus, vacuum pulsation and the pulsation ratio are important operating parameters that affect milking performance [5,34]. An ideal pulsation setting on the milking machine helps to maintain a high milk flow, limit animal discomfort, reduce the occurrence of new intramammary infections and stimulate the milk ejection reflex [29]. Interestingly, individual quarter-pulsation milking systems can prevent overmilking and reduce hyperkeratosis in Holstein cows [48]. Field experiments and research have shown that a relatively narrow range of pulsation rates and ratios is required to ensure teat-end health, udder health and to optimize milking speed [49]. However, it is well known that the pulsation ratio has a great influence on the milk flow rate, milking time, teat state and SCC of milk [4,5]. It was observed that the mean and maximum milk flow rate increased with increasing broader ratio (from 60:40 to 65:35 and to 70:30) [33]. It has also been observed that a wide pulsator ratio results in faster milking than a narrow pulsator ratio [50,51]. The praxis results showed that when using a quarter-individual milking system "MultiLactor" (Siliconform), milk yield per milking, average milk flow rate and machine-on time were significantly ($p < 0.001$) different after changing the pulsation ratio from 60:40 to 65:35 (Table 1) [6].

Table 1. Least square means for milk yield per milking, average milk flow rate and machine-on time after changing the pulsation ratio from 60:40 to 65:35 while using a "MultiLactor" (Siliconform) quarter individual milking system [6].

Pulsation Ratio	Total Milk Yield/Milking [kg]	Average Flow Rate [kg/min]	Machine-On Time [min]
60:40	$13.67^{a} \pm 0.33$	$1.75^{a} \pm 0.05$	$8.36^{a} \pm 0.25$
65:35	$14.00^{b} \pm 0.33$	$1.86^{b} \pm 0.05$	$8.03^{b} \pm 0.25$

$^{a, b}$ Means with different superscripts on the same column differ ($p < 0.001$).

Most modern milking equipment manufacturers set their pulsators within a relatively small range around the 60:40 ratio [43], as the milking speed has been optimized by keeping the liner open for about 0.5 to 0.6 s at each cycle [52]. However, the peak milk flow rate reaches its maximum at a pulsation ratio in the range of 60:40 to 70:30, depending on the properties of the liners used [46]. In addition, it was found that large ratios such as 70:30 resulted in shorter machine on-time and higher milk yields compared to ratios of 60:40 and 50:50 [50]. Likewise, increasing the pulsator ratio from 60:40 to 77:33 had no negative effects on teat tissue and had a positive impact on milk yield and shorter milking time [53]. Furthermore, studies have shown that peak milk flow rate consistently decreases after 70:30 to 80:20. The reason could be insufficient duration of pressure loading to overcome teat congestion [46]. It is worth noting that the correct setting of the pulsation ratio allows the pulsation chamber to recover to full atmospheric pressure for at least 150 milliseconds (d-phase) (15%) on each cycle. This helps to avoid teat congestion when using vacuum milking machines [47]. However, post-milking teat thickness tends to increase with the pulsation ratio, whereas it decreases significantly when the pulsation rate is between 20 and 80 cycles/min [29,35,47]. It has also been found that pulsation rates below 55 cycles/min affect udder health by increasing the risk of new intramammary infections [54].

3. Influence of the Teat Cup Liners on Teat Condition and Udder Health

Milking machine malfunctions, e.g., not the right liner and/or pulsators, the vacuum impeding blood and lymph circulation, lead to an unnatural strain on the teat tissue and thus to pain and immune reactions in the lactating animals. These artificial physiological and pathological changes in the circulatory system damage the teat ends, reduce the effectiveness of the udder's defense systems [53] and cause mastitis [34,55]. Thus, changes in teat condition can occur [29,34], which can be divided into short-, medium-, and long-term changes [56]. The most important short-term changes caused by circulatory disorders are discolored teats, ringing, swelling and openness of the teat canal [27,34]. These changes are reversible from one milking to another or even within a few hours. Swelling as a short-term effect of the milking machine on the teats can be measured using ultrasound [37]. However, the histological investigations of Stauffer et al., [11] have shown that enlargement of thick-walled veins in the teat tissue is the main reason for teat wall thickening in response to machine milking. It is noteworthy that each individual milking stimulates keratin growth in the teat canal to replace the keratin lost during milking [27]. If an unsuitable milking machine or misfitting teat liners are used for a long period, the milking machine attacks the teat end tissue, forms a ring of callus around the teat opening causing hyperkeratosis [24,30,35,37]. In addition, it has been observed that increased strength and thickness of the teat wall occurs as a result of congestion and oedema [37]. The blockage of the blood vessels leads to an accumulation of intravascular fluid [57] and could be a prerequisite for the development of an oedema called extravascular fluid build-up [58].

Gleeson et al. [53] have clearly shown that liner design had a greater impact on teat tissue changes and milking characteristics than pulsation settings. The magazine DairyNZ [59] confirmed in milked cows that liners have a major impact on milking performance, udder, and teat health. Furthermore, a teat cup liner must be specially designed for the animal's teat to prevent clogging of the teats and to allow proper blood flow. Therefore, it can be stated that a good liner achieves the following:

1. Seals both ends of the shell airtight.
2. Provides a properly sized mouthpiece and shaft that fits a range of teat shapes and sizes and minimizes liner slippage, clusters dropping and damage that can lead to mastitis.
3. Enables milking to be as quick and complete as possible to minimize congested teats, discomfort, and injury.
4. Is easy to clean and lasts a long time without changes.

New results from Holst et al., [60] showed that milk flow was higher with round liners than with triangular ones and the main milking time was shorter. As a result, it is better for the health and condition of the teats. Furthermore, previous studies have reported that calf suckling influences teat swelling less than a machine milking [61] (Table 2). However, SCC in lactating cows was slightly increased when claves suckled the cow in addition to machine milking compared to cows milked only by machine [62].

Table 2. Relative change in teat parameters, measured on ultrasonographic views, after machine milking and calf suckling Referring to Neijenhuis, Ref. [61].

Parameters	Calf Suckling	Machine Milking
Wall thickness (%)	6	26–50
Duct length (%)	7	19–28
Cistern diameter (%)	−9	−27–−65

It is noteworthy that the mechanical stress on the teat is significantly higher in machine milking than in the suckling calf [27], although the vacuum level and the pressure of the calf's mouth on the teat is significantly higher during suckling than in machine milking [63]. The explanation for these contradictions is that the cyclic compression of the liner during milking and the continuous vacuum are responsible for the stresses in machine milking, while when the calf suckles the pressure between the mouth and teat tissue drops to zero after each sip of milk [11].

4. Influence of Teat Cup Liners on the Milking Process

The teat cup liner is constantly in motion during the milking process. Therefore, it is one of the most active parts of the milking machine. Throughout their lifetime, they withstand the effects of cleaning agents and disinfectants as well as high temperatures [28]. However, Silicone material is largely temperature-neutral between −50 to +50 °C (no change in this temperature range in terms of flexibility and milking behavior) [23]. In addition, the more complex the milking system, the more the liner must perform throughout the milking process and over its lifetime. Optimum milking performance can only be achieved when all variables are considered, and material and design are perfectly matched [25]. Thus, for optimal milk removal, the continuous availability of milk from the cluster attachment to the point of extraction is crucial. The liner plays a big part in this as its movement provides continuous stimulation during milking, resulting in oxytocin release and continuous milk ejection until cluster detachment [1,64]. In all cases it has been shown that liners, milk yield and blind milking must be considered as risk factors for teat damage as they affect milking speed, overall vacuum levels, peaking and over-milking [29]. A balance should be struck between optimal milking speed and the risk of teat damage.

Many lactating animal farms have different teat sizes and teat shapes in their herds. With large teats, the liners often close tightly and strain the tissue in the teat, while with small teats, air gets into the teat cup and the cluster falls [24]. However, problems with teat cup attachment or poor adhesion to the teat during milking can result in milk particles splashing back onto the teat at high speed and becoming a source of infection if unsuitable liners are used. Such milk particles are still in the milking cluster of the previously milked lactated animal. It was observed that after milking a cow infected with streptococcus, these germs can be transmitted on to the next six to eight cows [65]. Therefore, several reports have shown that the teat cup liner transfers the shortcomings and mistakes in milking technique directly to the teat. In addition, using the wrong liner increases the risk of mastitis due to longer milking times, reduced milk flow and a higher stripping milk amount. Hillerton [66] observed that teat liners showed a significant impact on milking performance, cow behavior during milking, udder health and teat reaction. Thus, successful milking really requires perfectly fitting liners for milking machines and animal welfare of the entire herd. The new results showed that the use of the new liner "Stimulor® StressLess" (Siliconform, Germany) on a cow farm in Austria led to a significant increase in milk yield in all stages of lactation [24] (Figure 3).

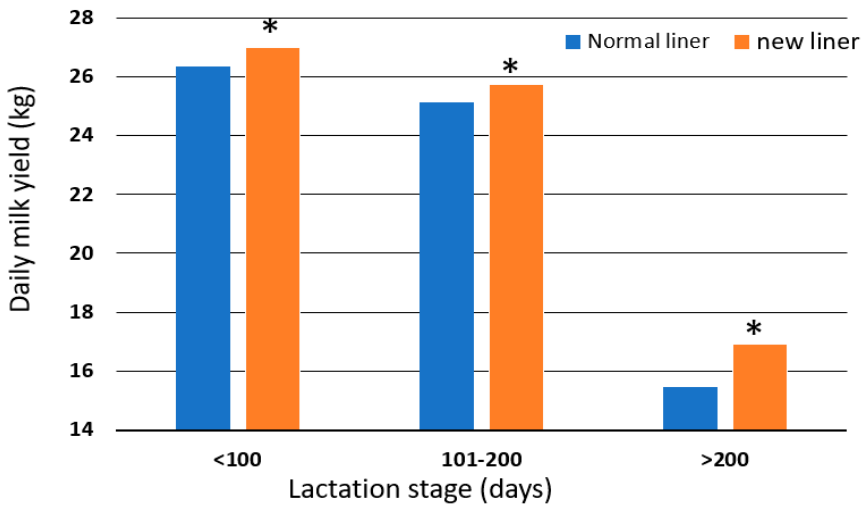

Figure 3. Daily milk yield before and after using the new liners in all examined cows (n = 42) in different stages of lactation on a dairy farm in Austria. * Mean significantly different ($p < 0.05$) in the same stage of lactation.

These new liners have unique properties that are excellent for maintaining teat health during machine milking for all lactating animals. One of their distinguishing features is the presence of the wavy construction design of its mouthpiece. Therefore, it adapts well to different cows and individual teat sizes in a herd. Furthermore, the liner supports positive welfare of lactating animals and the head vacuum is kept in the physiological range as it adheres particularly well to the teat.

5. How Do you Choose the Right Liner for Your Lactating Animals?

Choosing a liner is a complex and difficult task and an extremely important one. Therefore, when choosing the right liner, the milking machine, its vacuum settings, and the personal anatomy of the lactating animals must be considered. If the proposed liners fit the milking equipment, the milking performance of your lactating animals will in principle be comparable to other liners aimed at fast, efficient milking without negative effects. A stronger liner can also justify a gear change in this case. However, the design and management of the entire milking parlor affects the performance of the liners. If the liner is small, it narrows the milk drainage pathways and prevents high milk flow. On the other hand, if a small teat is milked with a liner that is too large, the tissue is overstretched and results in subsequent accumulation of connective tissue. The results are that the teats become hard and the milking ability of the cow deteriorates. Milking machines should be evaluated in their entirety to optimize the milking process. Teat cup liners must be carefully selected to fit the herd's teats and accommodate the machines. As a rule, teat liners are classified according to shaft length and shape, material, and construction. The head of the liner is designed to ensure a good fit to the base of the teat without restricting the connection between the gland- and teat cistern. Therefore, the correct liner selection must include the following objectives:

1. Maintains animal health: Ensures the teat is not damaged which can lead to problems of mastitis.
2. Increases milking efficiency: The right teat cup liners help keep the clusters in place and milk the animals faster.
3. Reduces animal stress: Ensure the liner does not cause pain leading to animal discomfort and animal handling issues.

It is noteworthy that the effects of teat liners that are not adapted to the herds udder shape are often underestimated. It is known that the teat cup liner takes on a massage function in machine milking. By collapsing (below the tip of the teat) the blood and liquid collected in the end of the teat is to be massaged back towards the bottom of the udder. However, teat liner shafts that are much too soft or too stiff cannot transmit sufficient force to the teat tip [67].

There are many high-quality milking machine liners on the market today, that can be used in conventional milking parlors or in automatic milking systems. Unfortunately, there are also cheap, poor-quality liners on the market, which many farmers complain about. It has long been known that silicone liners are better than synthetic liner for the following reasons [65]:

- Compared to synthetic rubber, silicone liners have good chemical and mechanical properties. This keeps them stable under different conditions.
- The extremely smooth surface does not give bacteria a chance to penetrate the silicone material during machine milking.
- Silicone teat cups are absolutely boil-proof and largely heat-stable. This means that cleaning solutions on these liners have no effect compared to synthetic liners.
- Silicone teats last three times as long as rubber materials and therefore remain economical despite being twice the price.

An interesting aspect is the liner shape and head structure. A round liner is the most common shape worldwide. Recent studies have shown that milking with triangular mouthpieces' chamber-ventilated liner leads to increased milk foam, which could potentially have a negative impact on milk quality [60]. A previous study showed that the type of liner used had a significant impact on keratinization and the frequency of cracked teat ends [68]. This means that herds milked with round teats had a 0.43 higher total keratinization score than herds milked with square teats. In addition, cows milked with round liners have on average 20% more cracked teat ends than cows milked with square liners.

Observations in practice have shown that teat shape and teat size vary greatly from animal to animal, including within the herd on the same farm, especially in camels [69] (Figure 4).

Figure 4. Different teat sizes and dimensions in lactating camels in the same herd [24].

The question of which liners best suits my milking machine, and my herd, can only be answered if the liners fit the morphological and anatomical conditions of the lactating udders. In practice, there is often no choice of liners according to the teat dimensions, but standard teat cup liners are often used. Most manufacturers of milking equipment have always strived to produce well-fitting teat liners. However, we cannot use an additional teat cup liner for each lactating animal on the farm. Hence, there were always some animals on the farms suffering from clinical or subclinical mastitis.

There is no teat liner that fits all lactating animals in a herd. Under these conditions, the company Siliconform, Germany, set itself the task of developing liners for all lactating animals, as the company has been in milking technology for 50 years and has a great amount of experience with all lactating animals such as cows [10,25], sheep, goats [7] and camels [69]. The company has development an exceptional teat liner for all lactating species. The name of the new liner is "Stimulor® StressLess" (Siliconform) (Figure 5). These new liners have unique properties that are excellent for maintaining teat health during milking in all lactating animals. One of its distinguishing features is the presence of the wave-shaped design of its head, which allows the "StressLess Stimulor" (Siliconform) to adapt well to the different teat sizes in a herd, thus ensuring consistent milking of lactating animals. In this way, the aim of the milking technology was achieved, which is to imitate the rhythmic process of calf suckling during machine milking as far as possible.

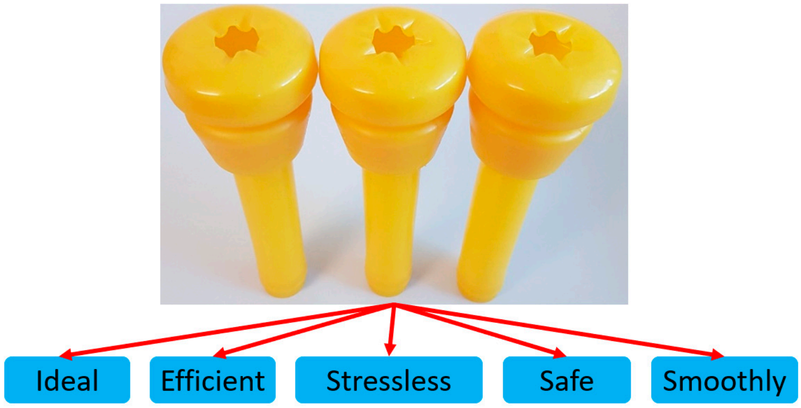

Figure 5. New teat cup liners (Stimulor® StressLess, Siliconform) for lactating animals.

Different teat sizes can only be optimally milked if the milking machine uses the integrated adaptive lip of the liner, which reacts to a pressure difference and allows air to flow in at the right moment. As a result, the vacuum of the liner head is kept in the physiological range. The new special silicone liner (Stimulor® StressLess, Siliconfrom) is ideal for all teat sizes and measurements of lactating animals and its design is of great importance for the acceptance of female lactating animals during the milking process. In practice, this means protection of the sensitive teat tissue and more comfort during milking. Furthermore, the new liners adhere particularly well and do not cause any slurping noises during milking. Finally, the new liner prevents injuries and thus makes a decisive contribution to better animal welfare and improved animal health.

6. Conclusions

The milking system should not adversely affect milk release and letdown which can reduce yield and alter composition.

Incorrect pulsator setting and/or high vacuum level and/or wrong pulsation ratios can result in disruptive machine milking and/or damage to the teat ends, which can lead to mastitis and reduced milk yield.

Liners are the only part of the milking machine that meet the teat of lactating animals, and their design is critical in udder health and for efficient milking.

The Stimulor® StressLess liner has a wavy construction. With the integrated adaptive lip, different teat sizes can be milked with the same liner.

Author Contributions: S.K. conceptualization and writing the original manuscript; M.W.P. revision of content and language improvement of the original manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Bruckmaier, R.M.; Blum, J.W. Oxytocin release and milk removal in ruminants. *J. Dairy Sci.* **1998**, *81*, 939–949. [CrossRef] [PubMed]
2. Parilova, M.; Stadnik, L.; Jezkova, A.; Stolc, L. Effect of milking vacuum level and overmilking on cow's teat characteristics. *Acta Univ. Agric. Et Silvic. Aemendelianae Brun.* **2011**, *59*, 193–202. [CrossRef]

3. Edwards, J.P.; O'Brien, B.; Lopez-Villalobos, N.; Jago, J.G. Overmilking causes deterioration in teat-end condition of dairy cows in late lactation. *J. Dairy Res.* **2013**, *80*, 344–348. [CrossRef]
4. Ferneborg, S.; Svennersten-Sjaunja, K. The effect of pulsation ratio on teat condition, milk somatic cell count and productivity in dairy cows in automatic milking. *J. Dairy Res.* **2015**, *82*, 453–459. [CrossRef]
5. Gasparik, M.; Duchacek, J.; Stadnik, L.; Novakova, V. Impact of milking settings optimization on milk quality, milking time, and milk yield in Holstein cows. *IOP Conf. Ser. Mater. Sci. Eng.* **2018**, *420*, 012073. [CrossRef]
6. Kaskous, S. Optimization of the pulsation ratio during the course of milk removal after using a quarter individual milking system "MultiLactor". *Int. J. Agric. Innov. Res.* **2018**, *6*, 284–289.
7. Kaskous, S. Laboratory Tests to Optimize the Milking Machine Settings with Air Inlet Teat Cups for Sheep and Goats. *Dairy* **2022**, *3*, 29–46. [CrossRef]
8. Caroprese, M.; Albenzio, M.; Marino, R.; Muscio, A.; Zezza, T.; Sevi, A. Behaviour, milk yield, and milk composition of machine-and Hand-milked Murgese mares. *J. Dairy Sci.* **2007**, *90*, 2773–2777. [CrossRef]
9. Baines, J. The role of machine milking in quality milk production and ensuring dairy cow welfare. *Cattle Pract.* **2010**, *18*, 48–52.
10. Kaskous, S. The effect of using quarter individual milking system "MultiLactor" on improvement of milk performance and milk quality of different dairy cows breeds in different farms. *Emir. J. Food Agric.* **2018**, *30*, 57–64. [CrossRef]
11. Stauffer, C.; Van der Vekens, E.; Stoffel, M.; Schweizer, D.; Bruckmaier, R.M. Increased teat wall thickness in response to machine milking. *J. Dairy Sci.* **2021**, *104*, 9082–9092. [CrossRef] [PubMed]
12. Neijnhuis, F. Teat Condition in Dairy Cows. Ph.D. Thesis, Faculty of Veterinary Medicine, Utrecht University, Utrecht, The Netherlands, 2004; pp. 1–189.
13. Hamann, J.; Osteras, O. Teat Tissue Reactions to machine milking and new infection risk. *Bull. Int. Dairy Fed.* **1994**, *297*, 34–41.
14. Mein, G.A.; Williams, D.M.D.; Reinemann, D.J. Effects of milking on teat end hyperkeratosis: 1. Mechanical forces applied by the teat cup liner and responses of the teat. In Proceedings of the 42nd Annual Meeting of the National Mastitis Council, Fort Worth, TX, USA, 26–29 January 2003; pp. 26–29.
15. Bobic, T.; Andrasic, D.; Mijic, P.; Gregic, M.; Baban, M.; Gantner, V. The effect of teat cup liner type on the teat condition of Holstein primiparous cows. *J. Cent. Eur. Agric.* **2018**, *19*, 766–771. [CrossRef]
16. Thomas, C.S.; Svennersten-Sjaunja, K.; Bhosrekar, M.R.; Bruckmaier, R.M. Mammary cisternal size, cisternal milk and milk ejection in Murrah buffaloes. *J. Dairy Res.* **2004**, *71*, 162–168. [CrossRef] [PubMed]
17. Kaskous, S.; Bruckmaier, R.M. Best combination of pre-stimulation and latency period duration before cluster attachment for efficient oxytocin release and milk ejection in cows with low to high udder-filling levels. *J. Dairy Res.* **2011**, *78*, 97–104. [CrossRef]
18. Kaskous, S. Physiology of lactation and machine milking in dromedary she-camel. *Emir. J. Food Agric.* **2018**, *30*, 295–303. [CrossRef]
19. Tuor, M.; Wellnitz, O.; Bruckmaier, R.M. The interplay of continuous milk ejection and milking system with and without prestimulation at different vacuum settings. *J. Dairy Sci.* **2023**, *106*, 3615–3624. [CrossRef]
20. Bruckmaier, R.M. Laktationsphysiologie. In *Kurzes Lehrbuch Milchkunde und Milchhygiene*; Krömker, V., Ed.; Parey in MVS Medizinverlage Stuttgart: Stuttgart, Germany, 2007; pp. 6–22.
21. Borghese, A.; Rasmussen, M.; Thomas, C.S. Milking management of dairy buffalo. *Ital. J. Anim. Sci.* **2007**, *6* (Suppl. S2), 39–50. [CrossRef]
22. Sandrucci, A.; Tamburini, A.; Bava, L.; Zucali, M. Factors affecting milk flow traits in dairy cows: Results of a field study. *J. Dairy Sci.* **2007**, *90*, 1159–1167. [CrossRef] [PubMed]
23. Kaskous, S. MultiLactor Melksystem, eine Revolution in der Melktechnik. In *Forschungsbericht, Abteilung der Forschung und Entwicklung*; Siliconform: Türkheim, Germany, 2016; pp. 1–40.
24. Kaskous, S. Importance of liner design and milking machine settings for optimal milking performance and welfare in camels. In Proceedings of the 6th Conference of the International society of Camelid Research and Development (ISOCARD), "The role of camel in food security and economic development" King Faisal University, Al Ahsa, Saudi Arabia, 12–16 March 2023; p. 37.
25. Kaskous, S. Optimization of milk performance and quality in dairy farms by using a quarter individual milking system "MultiLactor". *Int. J. Environ. Agric. Biotechnol.* **2020**, *5*, 943–952. [CrossRef]
26. Sagkob, S.; Rudovsky, H.-J.; Pache, S.; Herrmann, H.-J.; Bernhardt, H. Effects of different cluster types on teat end condition and milk release. *Landtechnik* **2010**, *65*, 27–30.
27. Odorcic, M.; Rasmussen, M.D.; Paulrud, C.O.; Bruckmaier, R.M. Review: Milking machine settings, teat condition and milking efficiency in dairy cows. *Animal* **2019**, *13*, 94–99.
28. Miekley, B. (K)ein Mythos, Bedeutung und Limitierung von Zitzengummis im Melkprozess. In Proceedings of the 22. Jahrestagung, Wissenschaftliche Gesellschaft der Milcherzeugerberater (WGM) e.V., an der Bayerischen Landesanstalt für Landwirtschaft in Grub, Bayern, Germany, 4–6 October 2022; pp. 11–13.
29. Vermaak, P.; Petzer, I.M.; Karzis, J. Effects of milking machine settings and teat liners on bovine udder health. *South Afr. J. Anim. Sci.* **2022**, *52*, 421–432. [CrossRef]
30. Neijenhuis, F.; Barkema, H.W.; Hogeveen, H.; Noordhuizen, J.P.T.M. Classification and longitudinal examination of callused teat ends in dairy cows. *J. Dairy Sci.* **2000**, *83*, 2795–2804. [CrossRef]
31. Krömker, V. Melken. In *Kurzes Lehrbuch Milchkunde und Milchhygiene*; Krömker, V., Ed.; Parey in MVS Medizinverlage Stuttgart: Stuttgart, Germany, 2007; pp. 23–46.

32. Reinemann, D.J.; Mein, G.A. Unravelling the mysteries of liner compression. In Proceedings of the Countdown Symposium, Tackling Strep Uberis, Melbourne, VIC, Australia, 8 June 2011; p. 10.
33. Spencer, S.B.; Shin, J.-W.; Rogers, G.W.; Cooper, J.B. Short communication: Effect of vacuum and ratio on the Performance of a Monoblock silicone milking liner. *J. Dairy Sci.* **2007**, *90*, 1725–1728. [CrossRef] [PubMed]
34. Penry, J.F.; Upton, J.; Mein, G.A.; Rasmussen, M.D.; Ohnstad, I.; Thompson, P.D.; Reinemann, D.J. Estimating teat canal cross-sectional area to determine the effects of teat-end and mouthpiece chamber vacuum on teat congestion. *J. Dairy Sci.* **2017**, *100*, 821–827. [CrossRef]
35. Hamann, J.; Burvenich, C.; Mayntz, M.; Osteras, O.; Haider, W. Machine induced changes in the status of the bovine teat tissue with respect to new infection risk. *Bul. IDF* **1994**, *2*, 13–22.
36. Ambord, S.; Bruckmaier, R.M. Milk flow-dependent vacuum loss in high-line milking systems: Effect on milking characteristics and teat tissue condition. *J. Dairy Sci.* **2010**, *93*, 3588–3594. [CrossRef]
37. Neijnhuis, F.; de Koning, K.; Barkema, H.; Hogeveen, H. The effect of machine milking on teat condition. *ICAR Tech. Ser.* **2001**, *7*, 33–40.
38. Pazzona, A.; Murgia, L. Effect of milking vacuum on leukocyte count in Buffalo milk. In Proceedings of the 24th International Conference on Agricultural Mechanization, Zaragoza, Spain, 1–4 April 1992; pp. 691–694.
39. Hamann, J. Effect of machine milking on teat end condition with special emphasis on infection risk. *World Rev. Anim. Prod.* **1990**, *25*, 9–12.
40. Sinapis, E.; Vlachos, I. Influence du niveau de vide de la machine a traire et des facteurs zootechniques sur le comptages de cellules somatiques chez les chevres locale grecque. In Proceedings of the 6th International Symposium on the Machine Milking of Small Ruminants, Athens, Greece, 26 September–1 October 1998; European Association for Animal Production (EAAP) Wageningen Academic Publishers: Wageningen, The Netherlands, 1999. No. 95. pp. 513–518.
41. Rasmussen, M.D.; Madsen, N.P. Effects of milk line vacuum, pulsator airline vacuum, and cluster weight on milk yield, teat condition, and udder health. *J. Dairy Sci.* **2000**, *83*, 77–84. [CrossRef] [PubMed]
42. Spencer, S.B. Milking machine, Principles, and design. In *Encyclopaedias of Dairy Sciences*, 2nd ed.; Fuquay, J.W., Ed.; Academic Press: San Diego, CA, USA, 2011; pp. 941–951.
43. Besier, J.; Bruckmaier, R.M. Vacuum levels and milk-flow-dependent vacuum drops affect machine milking performance and teat condition in dairy cows. *J. Dairy Sci.* **2016**, *99*, 3096–3102. [CrossRef] [PubMed]
44. Besier, J.; Lind, O.; Bruckmaier, R.M. Dynamics of teat-end vacuum during machine milking: Types, causes, and impacts on teat condition and udder health-A literature review. *J. Appl. Anim. Res.* **2016**, *44*, 263–272.
45. Dolezal, O.; Hlasny, J.; Jilek, F.; Hanus, O.; Vegricht, J.; Pytloun, J.; Matous, E.; Kvapilik, J. *Milk, Milking, Milking Parlours*; Agrospoj: Prague, Czechia, 2000; p. 241.
46. Mein, G.; Reinemann, D.; O'Callaghan, E.; Ohnstad, I. Where the rubber meets the teat and what happens to milking characteristics. In 100 years with liners and pulsators in machine milking. *Bull. Int. Dairy Fed.* **2004**, *388*, 431–446.
47. Hamann, J.; Mein, G.A. Teat thickness changes may provide biological test for effective pulsation. *J. Dairy Res.* **1996**, *63*, 179–189. [CrossRef]
48. Sterrett, A.E.; Wood, C.L.; McQuerry, K.J.; Bewley, J.M. Changes in teat-end hyperkeratosis after installation of an individual quarter pulsation milking system. *J. Dairy Sci.* **2013**, *96*, 4041–4046. [CrossRef]
49. Upton, J.; Penry, J.F.; Rasmussen, M.D.; Thompson, P.D.; Reinemann, D.J. Effect of pulsation rest phase duration on teat end congestion. *J. Dairy Sci.* **2016**, *99*, 3958–3965. [CrossRef]
50. Thomas, C.V.; Force, D.K.; Bremel, D.H.; Stressen, S. Effect of pulsation ratio, pulsation rate and teat cup liner design on milking rate and milk production. *J. Dairy Sci.* **1991**, *74*, 1243–1249. [CrossRef]
51. O'Callaghan, E.J. Effects of pulsation characteristics on machine yield, milking time, and cluster stability. *Ir. J. Agric. Food Res.* **1998**, *37*, 201–207.
52. Williams, D.M.; Mein, G.A.; Brown, M.R. Biological responses of the bovine teat to milking: Information from measurement of milk flow rate within individual pulsation cycles. *J. Dairy Res.* **1981**, *48*, 7–21. [CrossRef]
53. Gleeson, D.E.; O'Callaghan, E.J.; Rath, M.V. Effect of liner design, pulsator setting, and vacuum level on bovine teat tissue changes and milking characteristics as measured by ultrasonography. *Ir. Vet. J.* **2004**, *57*, 289–296. [CrossRef] [PubMed]
54. Osteras, O.; Ronningen, O.; Sandvik, L.; Waage, S. Field Studies shows associations between pulsator characteristics and udder health. *J. Dairy Res.* **1995**, *62*, 1–13. [CrossRef]
55. Bray, D.R.; Fowler, P.A.; Fialho, F.B.; Bucklin, R.A.; Yeralan, S.; Tran, T.; Braun, R.K. An automated system for monitoring milking system parameters. In Proceedings of the 37th National Mastitis Council Annual Meeting, St. Louis, MO, USA, 25–28 January 1998; pp. 127–136.
56. Mein, G.A.; Neijnhuis, F.; Morgan, W.F.; Reinemann, D.J.; Hillerton, J.E.; Baines, J.R.; Ohnstad, I.; Rasmussen, M.D.; Timmus, L.; Britt, J.S.; et al. Evaluation of bovine teat condition in commercial dairy herds: 1. Non-infectious factors. In Proceedings of the 2nd International Symposium on Mastitis and Milk Quality, Vancouver, BC, Canada, 13–15 September 2001; pp. 362–366.
57. Penry, J.F.; Crump, P.M.; Ruegg, P.L.; Reinemann, D.J. Short communication: Cow-and quarter-level milking indicators and their associations with clinical mastitis in an automatic milking system. *J. Dairy Sci.* **2017**, *100*, 9267–9272. [CrossRef]
58. Reinemann, D.J. The smart position on teat condition. In Proceedings of the New Zealand Milk Quality Conference, Hamilton, New Zealand, 18–19 June 2012; pp. 124–131.

59. DairyNZ. Correct teat cup liners will keep cows healthy and happy. *Management-Dairy News, 1 February 2018.* Available online: www.ruralnewsgroup.co.nz/dairy-management (accessed on 7 January 2018).
60. Holst, G.E.; Adrion, F.; Umstätter, C.; Bruckmaier, R.M. Type of teat cup and cluster ventilation affect vacuum conditions in the liner and milking performance in dairy cows. *J. Dairy Sci.* **2021**, *104*, 4775–4786. [CrossRef]
61. Neijnhuis, F. Spenen onder spanning. Tepels van de koe een goede indicator van melker en melkmachine. *Veeteelt* **1999**, *16*, 40–42.
62. Barth, K. Effects of suckling on milk yield and milk composition of dairy cows in cow-calf contact systems. *J. Dairy Res.* **2020**, *87*, 133–137. [CrossRef]
63. Rasmussen, M.D.; Mayntz, M. Pressure in the teat cistern and the mouth of the calf during suckling. *J. Dairy Res.* **1998**, *65*, 685–692. [CrossRef]
64. Bruckmaier, R.M.; Schams, D.; Blum, J.W. Continuously elevated concentrations of oxytocin during milking are necessary for complete milk removal in dairy cows. *J. Dairy Res.* **1994**, *61*, 323–334. [CrossRef] [PubMed]
65. Model, I.; Rudovsky, H.-J. Welcher Zitzengummi ist der richtige? *Milchpraxis* **1999**, *37*, 209–212.
66. Hillerton, J.E. Do liners differ? In Proceedings of the 44th Annual Meeting of the National Mastitis Council, Madison, WL, USA, 16–19 January 2005; pp. 133–138.
67. Reinemann, D.; Mein, G.A. Schonend(er) melken. *Elite Magazin für Milcherzeuger* **2013**, *6*, 64–66. Available online: www.elite-magazin.de (accessed on 7 January 2018).
68. Schukken, Y.H.; Petersson, L.G.; Rauch, B.J. Liners and teat end health. *NMC Annu. Meet. Proc.* **2006**, *45*, 183–196.
69. Kaskous, S. A new milking technology: "STIMULACTOR" for lactating camels. *J. Camel Pract. Res.* **2021**, *28*, 1–9. [CrossRef]