Comparison of two automatic milking systems regarding milk delivery and milk quality

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Abstract

In the last 20 years the number of dairy farms with automatic milking systems (AMS) increased continuously. Therefore, AMS have been developed steadily in technical terms and in regard to the used software. The aim of the present study was to investigate whether an AMS of the newest generation has advantages in efficiency and animal welfare compared with a previous model of the same manufacturer. Over a period of ten months, the data of 50 dairy cows were analysed. All cows were milked by a Lely Astronaut A2 as well as by a Lely Astronaut A4. As traits that could be influenced by the changeover of the milking system, milkings per cow and day, milking interval, time in AMS, milking time, milk yield, milk flow, and somatic cell count (SCC) were investigated. All traits under consideration were tested for differences between AMS with adequate generalized linear mixed models. The results of this investigations showed significant influences with the change to the new AMS regarding milking time, time in AMS, milk yield, milk flow, and milking intervals. Milking time and time in AMS decrease whereas milk yield, milk flow, and milking interval increase in the new AMS. For milkings per cow and day and SCC no significant differences between both systems could be found. In conclusion, the purchase of an AMS of the newest generation could bring advantages regarding time for milking, milk flow and milking interval. However, changes in udder health and efficiency cannot be achieved with technical innovations, exclusively.

Keywords: automatic milking system, animal welfare, milking time, milk flow, milking intervals

1. Introduction

The increasing demand for milk and dairy products leads to a new challenge for global dairy production. It is necessary to produce milk in sufficient quantity with high quality and an efficient use of resources. On the other side, it is important to improve the sustainability of dairy cattle farming. Therefore, automatic milking systems (AMS) have been developed and used in practice since the 1990s. As a consequence, farms with AMS are faced with the question whether or not an investment in a new AMS is efficient. To estimate the efficiency of AMS, information about behavior, milk delivery, and milk quality are important. The technical design and the functionality of an AMS could influence behavior and milking characteristics of dairy cows directly and indirectly.

The time in AMS can directly be influenced by the teat-cleaning and cup attachment of the AMS. The cleaning and stimulation of the teats results in oxytocin release and milk ejection (Bruckmaier et al., 2001). A proper teat preparation leads to a better milking performance with higher milk yields per milking, shorter milking time, and less bimodality (Sandrucci et al., 2007). The authors detected a significant influence of time between start of teat stimulation and cup attachment. The total machine-on time is also affected by the milk flow (Hogeveen et al. 2001). According to Berry et al. (2013), the milking time contributes to costs in dairy production systems.

The milk flow can be influenced by the stimulation technique of the AMS as well. Kolbach et al. (2013) rejected their hypothesis that a wash treatment would increase the average milk flow, but they found positive effects of the treatment on peak milk flow. Sandrucci et al. (2007) found out that the milk flow is affected by the premilking operations. On the other side, the milk flow is influenced by milkings per cow and day and milking interval as well (Trembley et al., 2016, Hogeveen et al., 2001).

The milk yield per AMS and day is used to evaluate the efficiency of an AMS (Castro et al., 2012). It depends on the individual milk yield per cow, which is influenced by milkings per cow and day, milk flow, and time in AMS (Trembley et al., 2016). The amount of the milkings per cow and day affect the milk yield of a cow. Hart et al. (2013) found, that cows which are milked three times a day produce more milk than cows which are milked twice a day. On the other side, the length of milking intervals had a significant influence on milk production (Hogeveen et al., 2001). The milk yield per AMS is influenced by the number of cows and the milk flow. This milk yield could be maximized by milking the maximum number of cows per AMS and on average 2.4-2.6 milkings per cow and day (Castro et al., 2012).

Thus, the milkings per cow per day play an important role regarding the efficiency of an AMS. Milkings per cow and day depend on the traffic system of the AMS. Bach et al. (2009) detected more visits to AMS with forced traffic systems compared with free traffic systems.

An important factor to describe the efficiency of an AMS is the cow-individual somatic cell count (SCC). It is not mainly influenced by the milking technique (Sharma et al. 2011), but the changeover of the milking system could have an effect on the SCC of a cow. De Koning et al. (2003) found the highest SCC in the first six months after the introduction of an AMS. The SCC normalizes and stabilizes after this period.

Gygax et al. (2007) compared two AMS from different manufacturers regarding milk yield, milking frequency, milking interval, teat-cup attachment success rate, and length of milking procedure. They found differences in teat-cup attachment success, duration of several milking phases, and milking frequency regarding different AMS. It cannot be said whether these results can be transferred to the comparison of two AMS of the same manufacturer.

Therefore, the aim of this investigation was to determine whether an AMS of the newest generation has advantages in efficiency and animal health compared with a previous model of the same manufacturer.

2. Materials and Methods

2.1. Animals, milking equipment and study design

The study took place on a commercial dairy farm in Germany. From a total of approximately 220 milking Holstein cows, 50 healthy cows were investigated over a period of ten months. The lactating cows were between their first and seventh parity and the days in milk were between 10 and 346. All investigated cows were milked by an Astronaut A2 as well as by an Astronaut A4. Both automatic milking systems are produced by Lely (Lely Holding S.à r.l., Maassluis, the Netherlands). The two AMS mainly differ in their design and in their software. The control unit of the A4 is not installed in the milking box like the A2 one. The two AMS differ regarding their dimensions, the type of animal entrance, the motor of the attachment arm, and the detection of the animal position inside the box. Furthermore, the number of possible different concentrates and the collected milking data are different between both AMS. On the other side, the cleaning system, the dimensions of the silicone liner, and the teat detection system are the same for both AMS. The teat cleaning, premilking and dipping are identical as well. The dimensions of both AMS are shown in Figure 1 and Figure 2.

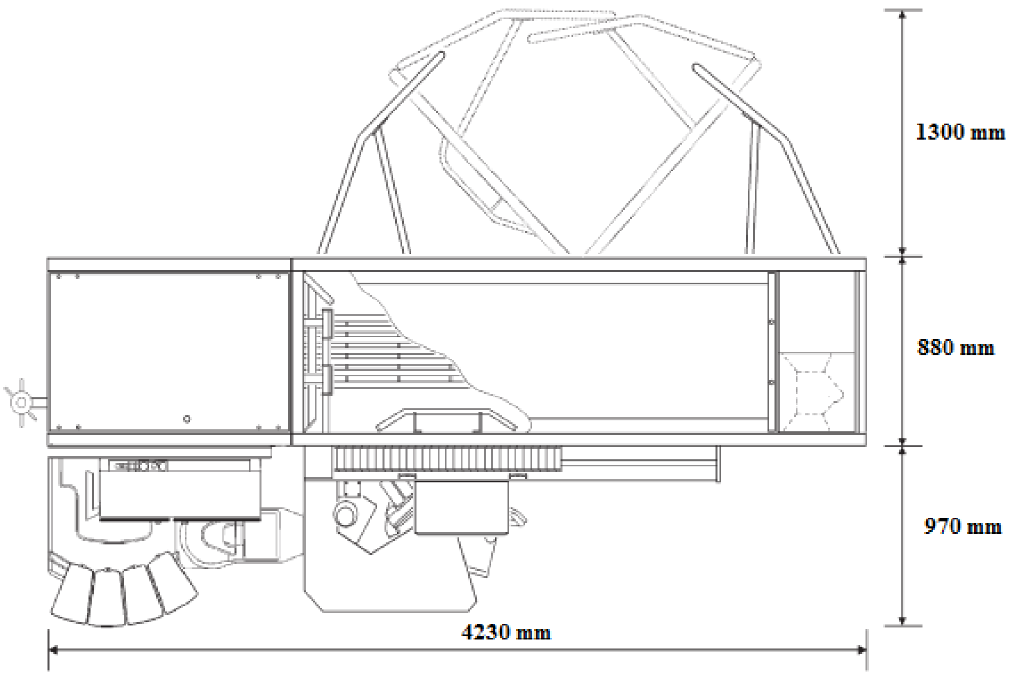

Figure 1. Dimensions of the Lely Astronaut A2 (Gündel, 2015)

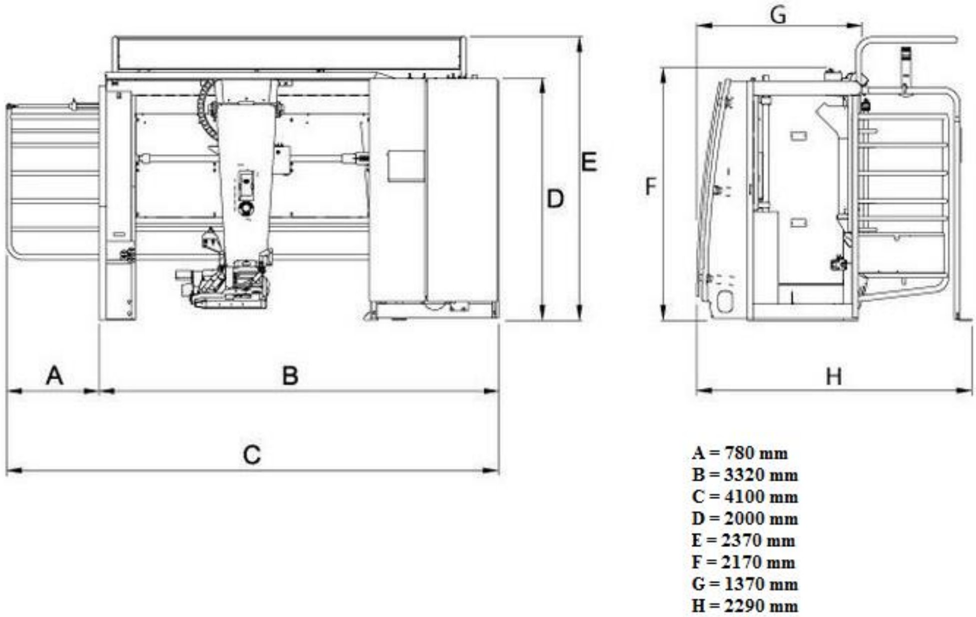

Figure 2. Dimensions of the Lely Astronaut A4 (Lely, 2012)

Both AMS used alternate pulsation with a pulsation rate of 60 min^{-1} and the pulsation ratio was 60:40 and 65:35 for the A2 and A4, respectively. The vacuum was adjusted to 42.5 kPa in the A2 and 44 kPa in the A4. The cow traffic of the A2 was semiforced, whereas the traffic system of the A4 was free. The number of cows per AMS varied between 45 and 50. The group of cows were milked in the A2 first and changed at the beginning of 2015 to the A4.

Any traits that could be influenced by the change of the AMS were investigated, such as milkings per cow and day, milking interval, time in AMS, milking time, milk yield, milk flow and SCC were investigated.

2.2. Statistical analysis

To show the effect of the changeover to an AMS of a new generation, a total of 25,522 data sets were analyzed using the SAS software package 9.4 (SAS Institute Inc., Cary, NC, USA). All animals in the third or higher parity were pooled into a single group. For each cow a period of three weeks was set as changeover period. The data from this period were not included in the calculation. The GLIMMIX procedure with logit link function and Poisson distribution was used to analyze the traits milkings per cow and day and milking interval.

The model to analyze the influence of the change on milkings per cow and day was the following:

$$y_{ijk} = \mu + CH_i + P_j + x_1 DIM + C_{jk} + \varepsilon_{ijk} \quad (1)$$

Where y_{ijk} is the observed number of milkings per cow and day; μ is the overall mean; CH_i is the fixed effect for time of changeover (i = 1 to 2);P_j is the fixed effect of parity j (j = 1 to 3); x_1DIM is the regression coefficient for days in milk x; C_{jk} is the random effect for cow k (k = 1 to 50) within parity j (j = 1 to 3); and ε_{ijk} is the independent residual.

The interaction between the time of changeover and the parity was added to the model, to calculate the milking interval. This resulted in the following model:

$$y_{ijk} = \mu + CH_i + P_j + x_1 DIM + x_1(DIM \times P)_i + C_{jk} + \varepsilon_{ijk} \quad (2)$$

Where y_{ijk} is the observed milking interval; μ is the overall mean; CH_i is the fixed effect for time of changeover (i = 1 to 2); P_j is the fixed effect of parity j (j = 1 to 3); x_1DIM is the regression coefficient for days in milk x; $x_1(DIM \times P)_i$ is the regression coefficient for day in milk x_1 at the time of changeover i; C_{jk} is the random effect for cow k (k = 1 to 50) within parity j (j = 1 to 3); and ε_{ijk} is the independent residual.

The MIXED procedure was used to analyze the influence of the changeover on milk yield, milk flow, milking time, time in AMS, and SCC.

The daily milk yield was used to analyze the influence of changeover on the milk yield. The Wilmink approach (Wilmink, 1987) was used to estimate regression coefficients for day in milk in order to achieve lactation curve shapes. This resulted in the following model:

$$y_{ijkl} = \mu + CH_i + P_j + TD_l + x_1W_1 + x_2W_2 + x_1(W_1xDIM)_j + x_2(W_2xDIM)_j + C_{jk} + x_1W_{1k} + x_2W_{2k} + \varepsilon_{ijkl} \quad (3)$$

Where y_{ijkl} is the observed milk yield; μ is the overall mean; CH_i is the fixed effect for time of changeover (i = 1 to 2); P_j is the fixed effect of parity j (j = 1 to 3); TDl is the fixed effect of test day l (l = 1 to 299); x_1W_1 is the regression coefficient for day in milk x_1; x_2W_2 is the regression coefficient x_2=EXP(-0.05 days in milk); $x_1(W_1$ x DIM) is the regression coefficient for day in milk x_1 within parity j; $x_2(W_2$ x DIM) is the regression coefficient x_2=EXP(-0.05 days in milk) within parity j; C_{jk} is the random effect for cow k (k = 1 to 50) within parity j (j = 1 to 3); x_1W_1 is the regression coefficient for day in milk x_1 within the cows; x_2W_2 is the regression coefficient for x_2=EXP(-0.05 days in milk) within the cows; and ε_{ijkl} is the independent residual.

To calculate the influence of the changeover on the milk flow, the following model was used:

$$y_{ijk} = \mu + CH_i + C_{jk} + \varepsilon_{ijk} \quad (4)$$

Where y_{ijk} is the observed milk flow; μ is the overall mean; CH_i is the fixed effect for time of changeover (i = 1 to 2); C_{jk} is the random effect for cow k (k = 1 to 50) within parity j (j = 1 to 3); and ε_{ijk} is the independent normally distributed residual.

With the following model the influence of the changeover on milking time and time in AMS was calculated:

$$y_{ik} = \mu + CH_i + MY + MF + (MY \times MF) + C_k + MY_k + MF_k + (MY \times MF)_k + \varepsilon_{ik} \quad (5)$$

Where y_{ik} is the observed milking time and time in AMS; μ is the overall mean; CH_i is the fixed effect for time of changeover (i = 1 to 2); MY is the mean milk yield; MF is the mean milk flow; (MY x MF) is the interaction between milk yield and milk flow; C_k is the random effect for cow k (k = 1 to 50); MY_k is the random regression coefficient for milk yield within cow k; MF_k is the random regression coefficient for milk flow within cow k; $(MY \times MF)_k$ is the interaction between milk yield and milk flow within cow k; and ε_{ik} is the independent normally distributed residual.

The following model was used to describe the influence of the changeover of the AMS on the SCC:

$$y_{ik} = \mu + CH_i + x_1DIM + C_k + x_1CDIM_k + \varepsilon_{ik} \quad (6)$$

Where y_{ik} is the natural logarithm of observed SCC; μ is the overall mean; CH_i is the fixed effect for time of changeover (i = 1 to 2); x_1DIM is the regression coefficient for day in milk x_1; C_k is the random effect for the individual cow k (k = 1 to 50); x_1CDIM_k is the random cow-individual regression coefficient k for day in milk x_1; and ε_{ik} is the independent normally distributed residual.

3. Results

The mean values of both AMS regarding milkings per cow and day, milking interval, time in AMS, milking time, milk yield, milk flow, and SCC are shown in Table 1.

Table 1. Means and 95% confidence intervals (CI) for milkings per cow and day, milking interval, time in AMS, milking time, milk yield, milk flow, and SCC in the Lely Astronaut A2 and the Lely Astronaut A4

Trait	**A2**	**CI**		**A4**	**CI**	
		Lower	**Upper**		**Lower**	**Upper**
milkings per cow and day	2.9	2.64	3.16	2.9	2.52	3.45
milking interval (hh:minmin ± min)	07:49	07:30	08:10	08:10	07:49	08:31
time in AMS (minmin:ss ± s)	06:36	05:18	07:48	06:24	05:06	07:36
milking time (minmin:ss ± s)	04:30	03:12	05:48	04:30	03:12	05:48
milk yield (kg per cow and day)	37.7	35.7	39.7	41.0	38.9	43.1
milk flow (kg min^{-1})	2.7	2.5	2.9	3.1	2.9	3.3
SCC	48,828	40,431	58,974	48,492	40,205	58,481

The milking time differed significantly between both AMS ($p = 0.0199$). Cows were milked in average 270 s (4 min 30 s) in the A2 and 269 s (4 min 30 s) in the A4. The time in AMS was significant shorter ($p < 0.0001$) for the A4 as well. It was for A2 6 min 36 s and A4 6 min 24 s. Both AMS differed significantly regarding daily milk yield ($p < 0.0002$). The milk yield increased by 3.3 kg with the changeover of the AMS. The differences between both AMS regarding milk flow were significant as well ($p < 0.0001$). The milk flow was 2.7 kg min^{-1} in the A2 and 3.1 kg min^{-1} in the A4. The milk flow increase with the change of the AMS. The milking interval was 7 h 49 min and 8 h 10 min for the A2 and for the A4, respectively. It differed significantly between both AMS (< 0.0001). The milking interval was longer for the A4 than for the A2. For milkings per cow no significant differences between both systems could be found. A significant influence of the changeover of AMS on SCC could not be detected as well (Figure 3).

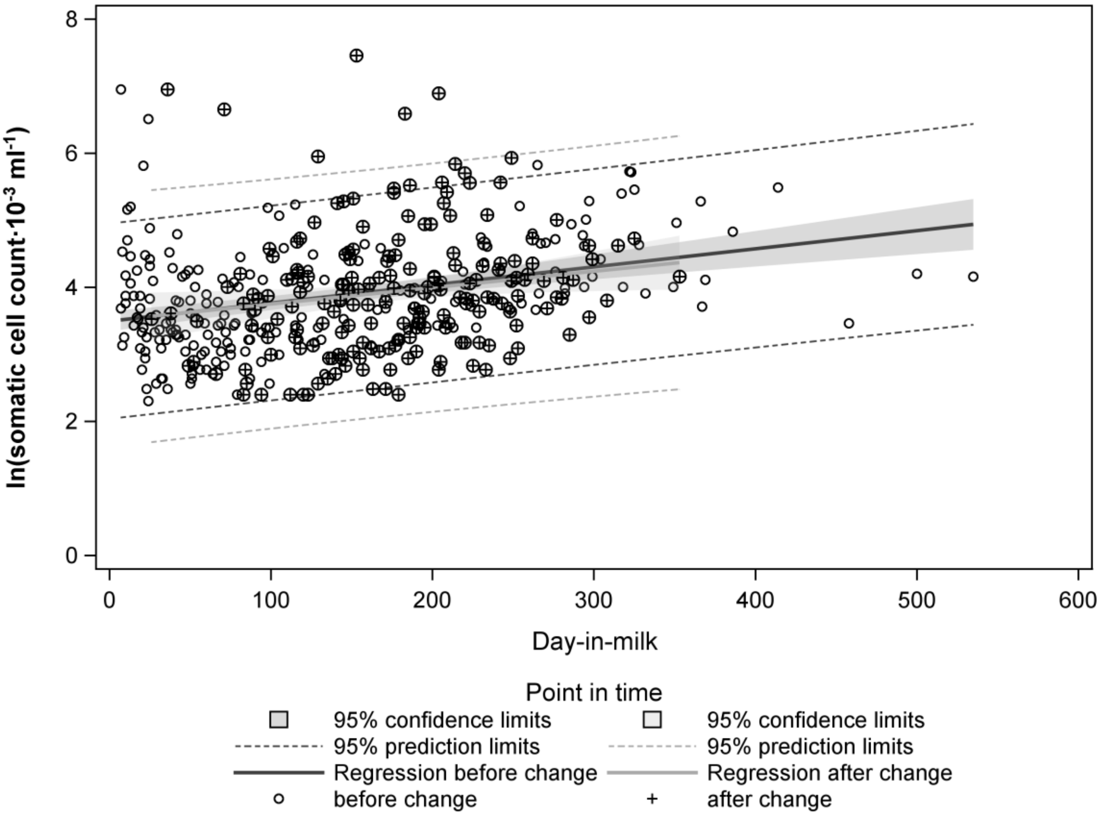

Figure 3. Regression of somatic cell count depending on day in milk before and after changeover of the AMS

4. Discussion

One of the key factors influencing the decision of new investment is the economic gain a producer will achieve with a new milking system (Hogeveen et al., 2004). Therefore, the efficiency of a milking system play an important role.The milk yield per AMS and day is used to evaluate the efficiency of an AMS. This depends on individual milking time, because longer milking times reduce the milking capacity of an AMS (Castro et al., 2012). In this investigation the milking time as well as the time in AMS was significantly less in the Astronaut A4 compared with the Astronaut A2. Although the milking time differed significantly between both AMS, from a practical point of view a shortening of the milking time to a second can be neglected. Regarding the time in AMS, it could be assumed that the technical development had improved the functionality of the cleaning brush and the teat cup attachment, with the help of faster imaging software and laser technology. The milking capacity is influenced by the attachment technology (Kaufmann et al., 2001). The whole milking process is optimized by finding the teats quickly and accurately. This leads to a shorter milking time with better milk delivery. Sandrucci et al. (2007) confirm the importance of the time between stimulation and milking for the milk flow. Besides the technical equipment, the milk flow influences the milking time (Sandrucci et al., 2007). Therefore, the milk flow is an indicator for the efficiency of a milking system. An increasing milk flow reduces the milking time without influencing the milk yield (Köhler, 2002). In this investigation the milk flow was higher in the A4 than in the A2. A reason could be a better stimulation of the udder, because it influences decisively the milk delivery (Bruckmaier and Blum, 1996, Sandrucci et al., 2007, Kolbach et al., 2013). The different milking vacuum of both AMS could be a reason for the increasing milk flow as well. The vacuum of the A4 is higher and according to Bade et al. (2009) a higher vacuum increases the milk flow. The teat-end vacuum of both AMS should be compared. An important indicator for the efficiency of a milking system is the milk yield (Castro et al., 2012). With the changeover to the A4 the milk yield of the herd increases from 37.7 kg to 41.0 kg per cow and day. The milk yield is influenced by the milking technique as well as the management or the genetics (M’Hamdi et al., 2012). In this study the same cows were milked with both AMS so the influence of genetics can be excluded. With the changeover of the AMS, the housing conditions changed as well. The lying cubicles changed and the herd size decreased. It could be assumed that this had a higher influence on the milk yield than the milking technique. This should be tested in further investigations. In this investigation the milking interval increases by 21 min with the changeover of the AMS. This reduces the efficiency of the A4 because an increasing milking interval leads to decreasing milkings per cow and day. The milkings per cow and day influence the efficiency of an AMS as well (Gygax et al., 2007). It is influenced by the number of AMS in the barn (Tremblay et al. 2016) as well as by cow traffic (Jacobs and Siegford, 2012). The more AMS are in the barn, the higher is the number of milkings per cow and day. Free cow traffic results in more milkings per cow and day compared with forced traffic. In this investigation neither the number of AMS per barn nor the traffic system influences the milkings per cow and day. Regarding SCC no significant differences between both systems could be found. The milking technique is not the main influencing factor of the individual SCC of a cow (Sharma et al., 2011). De Koning et al. (2003) found out that after the introduction of a new milking system the SCC normalized after a short time. In contrast, an increasing milking interval results in an increasing SCC (Mollenhorst et al., 2011).

The results of the present study show that a purchase of an AMS of the newest generation could have advantages, but changes in milk delivery, udder health, and efficiency cannot only be realized with technical development.

5. Conclusions

It can be concluded, that the change to an AMS of the newest generation could influence milk delivery and milk quality positively. The results of this investigations showed significant influences with the change to the new AMS regarding milking time, time in AMS, milk flow and milking intervals. Milking time and time in AMS decrease whereas milk yield, milk flow, and milking interval increase in the new AMS. For milkings per cow and day and SCC no significant differences between both systems could be found. The decrease of milkings per cow and day with simultaneous increasing milk yield suggests a better efficiency of the A4. The purchase of an AMS of the newest generation could bring advantages regarding time for milking, milk flow and milking interval. However, changes in milk delivery, udder health, and efficiency cannot be achieved with technical innovations, exclusively. In this investigation, the change of the barn environment, along with the changeover of the AMS, might have had a higher influence on the examined traits.

Acknowledgements

References

Bach, A., M. Devant, C. Igleasias, A. Ferrer, 2009. Forced traffic in automatic milking systems efficiently reduces the need to get cows, but alters eating behavior and does not improve milk yield of dairy cattle. Journal of Dairy Science 92 (3), 1272-1280. http://dx.doi.org/10.3168/jds.2008-1443

Bade, R.D., D.J. Reinemann, M. Zucali, P.L. Ruegg, P.D. Thompson, 2009. Interactions of vacuum, b-phase, and liner compression on milk flow rates in dairy cows. Journal of Dairy Science 92 (3), 913-921. http://dx.doi.org/10.3168/jds.2008-1180

Berry, D.P., B. Coughlan, B. Enright, S. Coughlan, M. Burke, 2013. Factors associated with milking characteristics in dairy cows. Journal of Dairy Science 96 (9), 5943-5953. http://dx.doi.org/10.3168/jds.2012-6162

Bruckmaier, R.M., J. Macuhova, H.H.D. Meyer, 2001. Specific aspects of milk ejection in robotic milking: a review. Livestock Production Science 72 (1-2), 169-176. http://dx.doi.org/10.1016/S0301-6226(01)00277-9

Bruckmaier, R.M., J.W. Blum, 1996. Simultaneous recording of oxytocin release, milk ejection and milk flow during milking of dairy cows with and without prestimulation. Journal of Dairy Research 63 (2), 201-208.

Catsro, A., J.M. Pereira, C. Amiama, J. Bueno, 2012. Estimating efficiency in automatic milking systems. Journal of Dairy Science 95 (2), 929-936. http://dx.doi.org/10.3168/jds.2010-3912

Gündel, S., 2015. Vergleich zweier automatischer Melksysteme, hinsichtlich der Reaktion der Milchkühe auf technische Neuerungen, anhand ausgewählter Merkmale. B.Sc. Thesis, Albrecht Daniel Thaer-Institute of Agricultural and Horticultural Sciences, Faculty of Life Sciences, Humboldt University Berlin, Berlin, Germany, 16

Gygax, L., I. Neuffer, C. Kaufmann, R. Hauser, B. Wechsler, 2007. Comparison of Functional Aspects in Two Automatic Milking Systems and Auto-Tandem Milking Parlors. Journal of Dairy Science 90 (9), 4265-4274. http://dx.doi.org/10.3168/jds.2007-0126

Hart, K.D., B.W. McBride, T.F. Duffield, T.J. DeVries, 2013. Effect of milking frequency on the behavior and productivity of lactating dairy cows. Journal of Dairy Science 96 (11), 6973-6985. http://dx.doi.org/10.3168/jds.2013-6764

Hogeveen, H., K. Heemskerk, E. Mathijs, 2004. Motivations of Dutch farmers to invest in an automatic milking system or a conventional milking parlour. In *Automatic milking: a better understanding.* Eds., A. Meijering, H. Hogeveen, C.J.A.M. de Koning, Wageningen Academic Publishers, 56-61

Hogeveen, H., W. Ouweltjes, C.J.A.M.d. Koning, K. Stelwagen, 2001.Milking interval, milk production and milk flow-rate in an automatic milking system. Livestock Production Science 72 (1-2), 157-167. http://dx.doi.org/10.1016/S0301-6226(01)00276-7

Jacobs, J.A., J.M. Siegford, 2012. Invited review: The impact of automatic milking systems on dairy cow management, behavior, health, and welfare. Journal of Dairy Science 95 (5), 2227-2247. http://dx.doi.org/10.3168/jds.2011-4943

Kaufmann, R., A. Ammann, R. Hilty, 2001. Influence of technical capacity and construction on the economic efficiency of the AMS. In *5th Conference Construction, Engineering and Environment in Livestock Farming.* Stuttgart, Germany , March 6-7, University of Hohenheim, Ed., Association for Technology and Structures in Agriculture (KTBL). 248-253

Köhler, S.D., 2002.Nutzung von Prozessparametern automatischer Melksysteme für die Erkennung von Eutererkrankungen unter Verwendung der Fuzzy Logic. Doctoral Thesis, Faculty of Agriculture and Horticulture, Humboldt University Berlin, Berlin, Germany.

Kolbach, R., K.L. Kerrisk, S.C. Garcia, 2013. Short communication: The effect of premilking with a teat cup-like device, in a novel robotic rotary, on attachment accuracy and milk removal. Journal of Dairy Science 96 (1), 360-365. http://dx.doi.org/10.3168/jds.2012-5477

Koning, C.J.A.M.d., B.A. Slaghuis, Y.v.d. Vorst, 2003. Robotic milking and milk quality: effects on bacterial counts, somatic cell counts, freezing point and free fatty acids. Italian Journal of Animal Science 2 (4), 291-299. http://edepot.wur.nl/185561

LELY, 2012. Lely Holding S.à r.l.. http://www.lely.com/uploads/unzipped/Lely_Astronaut_A4_Operator_EN/#35469 Accessed May 25, 2016.

M'hamdi, N., M. Bouallegue, M.B. Hamouda, S. Frouja, S.K. Brar, Y. Ressaissi, 2012. Effects of Environmental Factors on Milk Yield, Lactation Length and Dry Period in Tunisian Holstein Cows. In *Milk Production – An Up-to-Date Overview of Animal Nutrition, Management and Health*, Prof. Narongsak Chaiyabutr (Ed.), InTech. http://dx.doi.org/10.5772/50803

Mollenhorst, H., M.M. Hidayat, J. van den Broek, F. Neijenhuis, H. Hogeveen, 2011. The relationship between milking interval and somatic cell count in automatic milking systems. Journal of Dairy Science 94 (9), 4531-4537. http://dx.doi.org/10.3168/jds.2011-4244

Sandrucci, A., A. Tamburini, L. Bava, M. Zucali, 2007. Factors Affecting Milk Flow Traits in Dairy Cows: Results of a Field Study. Journal of Dairy Science 90 (3), 1159-1167. http://dx.doi.org/10.3168/jds.S0022-0302(07)71602-8

Sharma, N., N.K. Singh, M.S. Bhadwal, 2011. Relationship of Somatic Cell Count and Mastitis: An Overview. Asian Australasian Journal of Animal Science 24 (3), 429-238. http://dx.doi.org/10.5713/ajas.2011.10233

Tremblay, M., J.P. Hess, B.M. Christenson, K.K. McIntyre, B. Smink, A.J. van der Kamp, L.G. de Jong, D. Döpfer, 2016. Factors associated with increased milk production for automatic milking systems. Journal of Dairy Science 99 (5), 3824-3837. http://dx.doi.org/10.3168/jds.2015-10152

Wilmink, J.B.M., 1987. Comparison of different methods of predicting 305-day milk yield using means calculated from within-herd lactation curves. Livestock Production Sciences 17, 1-17. http://dx.doi.org/10.1016/0301-6226(87)90049-2