# MAIN PAPER

**Automation in dairy cattle milking: experimental results and considerations**

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**ABSTRACT**

The results of two experimental programs financed to the Istituto Sperimentale per la Zootecnia are presented. The objective of the two Italian programs was to verify if automatic milking is a suitable practice for Italian dairy system. Results are summarised and compared to those obtained in other international projects. Results refer to animal behaviour, milk yield, milk quality, and animal welfare. In a trial comparing cows milked with an automatic milking system and cows milked in a milking parlour, we observed that when the temperature and humidity are very high cows reduce their activity, have lower milking frequency and milk yield than in cold seasons. In comparison to milking parlour, automatic milking system did not increase milk yield which was affected significantly by season, stage of lactation, parity, season per treatment and parity per treatment. The causes of the negative results obtained by this group and by other international groups are discussed. We also presented the results obtained in four trials whereby four appetizers or flavourings were tested to improve efficiency of automatic milking system. Comparing the two milking systems, automatic milking determined a worsening of milk quality, but from these data is not possible to exclude the possibility to use automatic milking for Grana Padano and Parmigiano Reggiano-type cheeses. Animal welfare is not negatively influenced by automatic milking system, which has the potentiality to improve the control and care of cows.

*Key words: Dairy cattle, Automatic milking.*

**RIASSUNTO**

AUTOMAZIONE DELLA MUNGITURA DELLE BOVINE DA LATTE: RISULTATI SPERIMENTALI E CONSIDERAZIONI

A partire dal 1998 in Europa si sono diffusi i robot di mungitura, che effettuano automaticamente l’attacco dei gruppi di mungitura, eliminando quindi ogni intervento dell’uomo in questa operazione. Nel 2003 vi erano almeno 2200 aziende, soprattutto europee, che utilizzavano almeno un sistema di mungitura automatico. La possibilità di ridurre i costi del lavoro è la principale motivazione che ha spinto gli allevatori ad introdurre nei loro allevamenti un sistema di questo genere, ma ve ne possono essere ancora delle altre: consentire alle vacche di avere un comportamento più naturale, aumentare la produzione di latte, dare all’azienda una immagine positiva, migliorare le condizioni di lavoro, rendere più socialmente accettabile il lavoro dell’allevatore. All’Istituto Sperimentale per la Zootecnia è stato finanziato un progetto dal Ministero delle Politiche agricole e Forestali, per verificare se la mungitura automatica è una pratica idonea al sistema produttivo italiano. La prima fase della ricerca è stata quella di osservare ciò che accadeva in un allevamento sperimentale dopo l’introduzione di un robot di mungitura; la seconda quella di confrontare due gruppi di bovine munte in un sistema automatico e in sala di mungitura tradizionale, al fine di valutare gli effetti sul benessere animale, la produzione e la qualità del latte. Inoltre sono riportati i risultati di un altro esperimento finanziato dalla Regione Lombardia, riguar-
Koning and Rodenburg (2004). In 2003 about 2200 commercial farms had at least one milking robot. Most of them had middle-size herds and 1 to 3 boxes; however there are some examples of large dairy herds adopting an AMS. Automatic milking requires a big financial investment that is justified in those countries and conditions where labour costs are high. For this reason, AMS are diffused where labour is expensive and the average size of the farms is small or middle. In table 1 there are some data concerning the distribution of automatic milking systems worldwide. Most of them are in Europe (particularly in The Netherlands, France, Sweden, Denmark, and Germany) and only a very few are in USA, where the production costs are limited through the high number of cattle per herd.

The possibility to reduce labour costs is not the

Table 1. Diffusion of milking robots (year 2002). From de Koning and Van der Vorst (2002).

| Country        | AMS (n.) | Country        | AMS (n.) |
|----------------|----------|----------------|----------|
| The Nederlands | 520      | Finland        | 29       |
| France         | 269      | Switzerland    | 25       |
| Sweden         | 209      | Italy          | 25       |
| Denmark        | 200      | Norway         | 19       |
| Japan          | 70       | Ireland        | 15       |
| Canada         | 55       | USA            | 9        |
| Spain          | 40       | Israel         | 5        |
| Belgium        | 36       | Austria        | 5        |
| UK             | 33       | TOTAL          | 1745     |

AMS: automatic milking system
only reason that induced the farmers to adopt an AMS. Additional motivations are: more natural behaviour of cows, increased milk yield, a better image of the farm, better labour conditions, a more social life of the farmers etc.

Automatic milking is not simply the adoption of a new type of milking machine, but it is especially a new method to rear cattle, which requires some changes in feeding and housing and which has some relevant consequences on milk yield, milk quality, cows’ behaviour and welfare.

In order to study the effects of the introduction of automatic milking, an important European Program was funded. Some other experimental projects were also carried out thanks to national or regional programs. One of these was financed to the Istituto Sperimentale per la Zootecnia, Cremona, Italy, by the Italian Ministry of Agricultural and Forestry Policies. The first step of this program was to observe what happened in an experimental herd after changing from mechanical to automatic milking. A second step was to compare two groups of cows milked with mechanical or automatic milking machine in order to verify the effects on animal welfare, milk production and milk quality. In addition, two further experiments, funded by Regione Lombardia, were conducted to study milk persistency of cows milked with AMS and improvement of efficiency of AMS through feeding management. The final objective of both programs was the verify if automatic milking is a suitable practice for Italian dairy system. In this paper the results of these programs are presented, compared to those obtained by other European groups, and the future perspective of automatic milking are discussed.

The data that are presented have been already published (Abeni et al., 2002; Speroni et al., 2003; Migliorati et al., 2003; Pirlo et al., 2004; Speroni et al., 2004), even thought in a preliminary form in many cases, because most results of the experiments have been just submitted for publication or are still in progress.

**General discussion**

**Animal behaviour**

The major difference between automatic and traditional milking is that in the first case cows are free to go to the milking machine when they want and milkings are distributed throughout the day. In figure 1 the patterns of milkings and of milking intervals we have observed are presented (Speroni et al., 2003). The milkings were performed rather continuously, but not constantly over the day: the drops correspond with cleaning of AMS. The lowest number of milkings was observed early in the morning, the highest was observed just few hours later. This peak is consistent with the feeding schedule of total mixed ration and the lazy cows fetching (between 06.00 and 09.00). The average milking interval is high because most cows do not go to milking during the night, otherwise the second peak in the afternoon corresponds to a short average milking interval because most cows have already been milked in the morning. The overall milking interval was 9 h 23 m 50 s (figure 2); 12.5 % of the milkings occurred after an
interval of 6 h or less and 19% longer than 12 h; the 4.5% of all milking intervals were longer than 16 h.

Milk yield

Cows are motivated to go to the AMS because there they are fed some concentrate through an automatic feeder. The consequence is that cows are generally milked more than 2 times a day, with some exceptions (Table 2). Potentially, this could have a great effect on milk yield because it is well known that the increase of milking frequency has a positive effect on milk yield (Smith et al., 2002). Milking frequency depends on several managing and environmental factors such as cow traffic, temperature and humidity, feeding system. We have observed a reduction of presentation to AMS in spring and summer if the Temperature and Humidity Index (Ingraham, 1976), is over 70 for a prolonged period of time (Figure 3).

Percentage of lazy cows (animals that, without any apparent cause, do not go to the AMS) influences milking frequency. This percentage is influenced by herd density, concentrate composition and amount fed in the AMS (Rodenburg and Wheeler, 2002), meaning that several managing aspects should be adjusted in order to stimulate

Table 2. Literature data for milking frequency under automatic milking system.

| Author                      | Average milking frequency | Traffic or condition                      |
|-----------------------------|---------------------------|------------------------------------------|
| de Konning and Ouweiltsjes, 2000 | 2.5                       |                                           |
| Wendl et al., 2000          | 2.4                       | guided                                   |
| van’t Land et al., 2000     | 2.93                      | free                                     |
|                             | 2.93                      | selectively guided                       |
|                             | 2.71                      | guided                                   |
| Hopster et al., 2000        | 3.0                       | guided                                   |
| Harms et al., 2002          | 2.29                      | free                                     |
|                             | 2.63                      | guided                                   |
|                             | 2.56                      | selectively guided                       |
| Svennersten-Sjaunja et al., 2000 | 2.38                    | confined                                 |
|                             | 1.94                      | grazing                                  |
| Spörndly and Wredle, 2002   | 2.49                      | grazing                                  |
|                             | 2.45                      |                                          |
| Ketelaar-da Lauwere et al., 2000 | 2.5-2.9                | free with selection in AMS               |
|                             | 3.1-2.8                   | free with selection before AMS           |
|                             | 2.9-2.8                   | free with selection before AMS and waiting area |
|                             | 3.0-3.3                   | guided with waiting area                 |
| Thune et al., 2002          | 2.56                      | guided                                   |
|                             | 2.39                      | selectively guided                       |
|                             | 1.98                      | free                                     |
| Abeni et al., 2002          | 2.85                      | selectively guided                       |
| Speroni et al., 2004        | 2.67                      | selectively guided winter and autumn     |
|                             | 2.51                      | selectively guided summer and spring     |
In order to stimulate the voluntary access of the cows into the AMS, we supposed to give concentrates added with highly attracting substances through the feeder in the AMS. In tables 3 there are the results of four experiments we conducted about the use of flavouring and appetizing substances to attract cows to the AMS. Forty Italian Friesian cows were used to test four concentrates fed in the AMS; the concentrates were added with: 1) in experiment 1 aromatic substances, a gustatory dominance of fenugreek flavour; 2) in experiment 2 a natural highly intensive sweetener; 3) in experiment 3 an aromatic sweetener; 4) in experiment 4 a test modifier, a strong liquor test with low flavour (Migliorati et al., 2003). We did not observe any significant difference and further trials have been done or are in progress to find out effective attracting substances. In table 4 the results of the experiment thereby we compared a group of cows milked with AMS with another group milked in a milking parlour (Pirlo et al., 2004). Total milk yield of both groups was not affected by milking system, however it was affected significantly by season, stage of lactation, parity season per treatment and parity per treatment (figure 3).

Most of the scientists and companies sustain that automatic milking increases milk yield. This is largely accepted, but the results of the experiments (Table 5) and data of field studies available till now are very inconsistent. In some cases they gave very promising results, with an increase of production ranging around 10% (Kruip et al., 2002; Shoshani and Chaffer, 2002), but the vari-

Table 3. Effect of different sources of appetizers and flavouring on milk yield (MY), visits to automatic milking system (visits), number of daily milkings (milkings), and milking interval (MI). Difference between treatments were never significant.

| Experiment 1 | MY (kg/d) | Visits (n) | Milkings (n) | MI (hh.mm.ss) |
|--------------|-----------|------------|--------------|---------------|
| Control      | 25.6      | 3.88       | 2.68         | 10.03.42      |
| Treatment: combination of aromatic substances | 25.7 | 3.75 | 2.64 | 9.30.05 |
| Experiment 2 | Control   | 24.1       | 3.58         | 2.34          | 10.25.16     |
| Treatment: natural highly intensive sweetener | 23.7 | 3.53 | 2.35 | 10.25.28 |
| Experiment 3 | Control   | 24.1       | 3.88         | 2.44          | 9.59.48      |
| Treatment: aromatic sweetener | 23.7 | 4.43 | 2.52 | 10.27.44 |
| Experiment 4 | Control   | 25.9       | 4.12         | 2.51          | 9.57.34      |
| Treatment: test modifier | 25.6 | 3.93 | 2.49 | 11.15.22 |

Table 4. Means and standard deviation of milk yield (Pirlo et al., 2004).

|          | n. | Mean (kg/d) | SD  |
|----------|----|-------------|-----|
| AMS primiparous | 30 | 27.1        | 8.83|
| AMS pluriparous  | 18 | 32.5        | 10.57|
| AMS Total       | 48 | 29.0        | 9.81|
| MP primiparous  | 39 | 28.3        | 7.03|
| MP pluriparous  | 18 | 29.4        | 13.16|
| MP Total        | 57 | 28.7        | 9.3  |

AMS: automatic milking system; MP: milking parlour.
ability is very large: between +16% and −35% as in the case of a Dutch study (de Koning and Rodenburg, 2004).

There are several causes of this inconsistency. Milking frequency influences milk yield, and if there are conditions reducing milking frequency, milk yield is also reduced, as happened in the experiment reported in figure 3. We observed that the detrimental effect of high THI in summer is greater with AMS than with traditional milking, because of the reduced activity of cows in AMS (figure 3).

Composition of herd can also explain some results: we have observed that heifers have a higher milking frequency than pluriparous, but they seem not to increase their milk yield (Speroni et al., 2004). Finally, the genetic level seems to be very important because it was observed that the reduction of milking intervals has greater effects with higher producing cows than with low producing cows (Hogeveen et al., 2001).

Although the motivations of farmers who adopt an AMS are namely the improvement of quality of life and the reduction of labour costs, the possibility to increase the milk yield is crucial for a large diffusion of milking robots because it is necessary to finance the large investment that an AMS requires. We know that 8 hours is the optimal distance between two milkings. This results can be achieved if all cows regularly and constantly go to the AMS. Several strategies can be considered for this aim, some of them are:

- to make the AMS a comfortable and attractive area;
- to feed a very attractive and healthy concentrate;
- to make easy the access to the AMS.

Abnormal milk

The general conditions of hygiene in milk production in EU are defined by the Commission Directive 89/362/EEC (1989), which requires that milk shall be inspected before milking, and not all elements can be applied to the automatic milking. A modification of the Directive was proposed in order to accept the inspection that the robot makes automatically on milk colour and conductivity, to find out abnormal milk (Rasmussen, 2004).

Milk quality

Milk quality is very important for the acceptance of automatic milking, especially in Italy where most of the milk produced is used for cheese making.

The third milking determines a reduction of milk fat and protein concentration (Smith et al., 2002), but some other milk characteristics are modified: casein percentage, percentage of casein on CP, percentage of free fatty acids, with important implications on cheese rate (Klei et al., 1997).

The field studies which have been done in the EU project (de Koning et al., 2004) pointed out several negative effects of automatic milking on milk quality concerning: there is a general increase of bacteria counts and somatic cell counts, a small decrease of milk protein and fat percentage, an increase of free fatty acids and an increase of freezing point. These studies revealed that cleaning of the milking equipment and milking cooling are critical factors in controlling bacteria counts and that there should be an appropriate management of infected cows to prevent the spreading of mastitis among cows milked with AMS.

Data from our experiments largely confirm results of field studies. In table 6, we have report-

| Authors | AMS (kg/d) | MP (kg/d) | % | P |
|---------|------------|------------|----|---|
| Svennersten-Sjaunja et al., 2000 | 24.3 | 22.8 | +6.75 | ns |
| Pomiès and Lefeuvre, 2001 | 21.7 | 23.0 | -5.6 | <0.05 |
| Daenicke et al., 2000 | 25.7 | 24.3 | +5.8 | ns |
| Hopster et al., 2000 | 33.4 | 34.9 | -2.6 | ns |
| Wagner-Storch and Palmer; 2003 | 26.1 | 25.6 | +2.3 | <0.05 |

AMS: automatic milking system; MP: milking parlour.
ed the data about some characteristics of milk yielded by cows milked with AMS or with milking parlour. We observed a decrease of fat percentage, an increase of SCC and of free fatty acids. Some technological characteristics are also negatively influenced by AMS: natural creaming and titratable acidity which are important parameters in long-ripened cheeses, such as Grana Padano or Parmigiano Reggiano. However, the expert cheese maker did not noticed any difference during the whole process. Weight loss during the first 7 months of ripening proceed correctly in both cheeses and no blowing was recorded. In a preceding study (Abeni et al., 2002) we did not observe any negative effects of AMS on technological characteristics of milk, but we obtained an improvement of curd firmness after the introduction of the AMS into the experimental farm in Cremona.

From these data is not possible to state if long-ripened cheeses can be produced with the milk deriving from an AMS, but the results seem promising and studies should be continued not to exclude the possibility to use automatic milking for Grana Padano and Parmigiano Reggiano-type cheeses.

Animal welfare
As for any other technology, automatic milking should respect animal welfare. The European research project had a special section about animal welfare and our project also took in consideration this issue.

Cows in an AMS are expected to visit the robot voluntarily. However, in a herd there are both high- and low-ranked cow, and lay-out and management should be in such a way to permit to give access to milking and feeding to both ranks. A second concern refers to the reactions of cows which are not allowed to pass gates. A third concern is the adaptation of cows passing from the traditional milking to AMS. A review on welfare of cows milked with AMS was made by Wiktorsson and Sørensen (2004).

In our experiment (Pirlo et al., 2004), we evaluated the capacity of heifers to cope the starting of lactation in an AMS and in a conventional system. We observed a slight difference in stress measure. Starting after calving, the cortisol values were generally higher in AMS than conventional milking (figure 4). In AMS group there were more cows with spike values of cortisol in blood, suggesting a chronic stress situation with a stronger responsiveness to any stress-like stimulus, such as bleeding. Nevertheless, we can that the effect we measured was negligible compared to the advantages for the animal and the farmers; in addition, there is a large agreement that AMS is largely comparable with traditional milking for the animal welfare (Wiktorsson and Sørensen, 2004).

Table 6. Least square means and standard error of milk parameters of primiparous cows in MP and AMS (Pirlo et al., 2004).

| Parameter                  | MP         | AMS         | P     |
|----------------------------|------------|-------------|-------|
| Fat %                      | 3.61±0.07  | 3.33±0.09   | 0.02  |
| Protein "                  | 3.54±0.04  | 3.50±0.03   | ns    |
| Lactose "                  | 5.17±0.03  | 5.17±0.02   | ns    |
| SCC ln (10³/ml)            | 4.37±0.15  | 4.81±0.11   | 0.02  |
| Urea mg/100 ml             | 24.69±0.46 | 25.12±0.34  | ns    |
| Freezing point °C          | -0.5293±0.0006 | -0.5291±0.0004 | ns   |
| FFA meq/100 g of fat       | 0.531±0.039 | 0.700±0.030 | 0.001 |
| Natural creaming % of fat  | 39.74±1.50 | 36.11±1.24  | 0.06  |
| Median fat globule Ø µm    | 4.55±0.11  | 4.61±0.08   | ns    |
| pH                         | 6.706±0.010 | 6.745±0.007 | 0.002 |
| Titratable acidity °SH/100 ml | 7.143±0.100 | 6.759±0.072 | 0.002 |
| Casein N % of N            | 75.73±0.39 | 75.62±0.25  | ns    |
| NPN                        | 5.49±0.13  | 5.72±0.09   | ns    |

AMS: automatic milking system; MP: milking parlour.
Animal characteristics and selection

Percentage of cows that should be culled changing from traditional to automatic milking is one of the main concerns of farmers, although it does not appear so relevant from an economical point of view. It seems also that this problem is less important than what appeared when the first milking robots were introduced into commercial herds.

We do not know studies about the percentage of cows which were culled because they were not suitable for such a milking; recently we proposed a form where the most relevant characters are evaluated. All the characters have a lower and a higher limit; but only some characters have limits that must be respected (Migliorati, 2003). The form can be used by the farmer before deciding to buy a milking robot and can be also used for the selection of cows in the perspective of a larger diffusion of milking robots.

Figure 4. Plasma cortisol in primiparous cows milked with AMS or milking parlour (MP)

Conclusions

Automatic milking is already a reliable technology which seems to be well accepted by farmer and consumer. A great EU project and many other national projects, as that we made in Italy, let us say that the automatic milking represents an opportunity to improve animal welfare and milk quality. Even though there are some negative results for milk quality, robot milks cows in a precise and regular way and this very promising for an improvement of milk quality. Even for welfare the results are very promising, because the difference in behavioural and physiological analyses observed between AMS and milking parlour are very little; but, above all, AMS gives the opportunity of a precise and continuous control of cows. The data given by the AMS are precious for early detection of several disorders and can put in evidence anomalies in behaviour and production. There are still some concerns about milk yield whose increase is lower than expected. For a further increase of milk yield, strategies to have more regular movement of cows to the AMS are needed.

Automation is still at the beginning in animal husbandry. In the future, the man will have the opportunity to change his work from a manual activity to control operations. Electronic will help him to care animals individually and precisely also if they are in large herds. Milking robot is the focal point of this process, may be because it does the most complicated operation. In the future, further electronic devices and biosensors will be added to it and cattle will be kept according their individual needs.

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