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Assessment of technical-productive aspects in Italian dairy farms equipped with automatic milking systems: A multivariate statistical analysis approach

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ABSTRACT

The aim of this study was to assess technical-productive aspects of dairy farms equipped with automatic milking system (AMS) in Northern and Central Italy. A survey was carried out on 62 dairy farms selected through convenience sampling with the following inclusion criteria: adoption of robotic milking for at least 1 yr and ability to provide farm data. Data were collected using a structured questionnaire to obtain a general description of farm characteristics and overall management practices. Through the combination of principal component analysis and k-means cluster analysis, the farms were allocated in 3 clusters. The identified clusters were described and afterward compared using one-way ANOVA or a chi-squared test. The main observed differences between clusters were the average number of lactating cows and AMS installed, average annual milk production, average AMS loading, average annual milk yield per full-time employee, average daily milk yield per cow and AMS, and the average annual veterinary costs per cow. cluster 1 (n = 24) included small-to-medium-sized semi-intensive farms with low AMS loading and low average daily milk yield per cow. In this farm typology, the AMS is not fully used and is likely perceived as a means to improve quality of life rather than profitability. Clusters 2 (n = 31) and 3 (n = 7) included, respectively, small-medium-sized and large intensive farms. These 2 farm typologies are characterized by an intensive approach to dairy cattle breeding, with average higher AMS loading, labor efficiency, and milk yield compared with the farms of cluster 1, likely due to better farm management. This classification could help dairy technicians give farmers customized management advice for the function of the cluster they belong to, and farmers falling in a specific cluster could evaluate whether they are reaching their objectives.
Key words: automatic milking system, multivariate statistical analysis, dairy farm classification

INTRODUCTION

Agriculture is one of the top 5 economic sectors with the highest potential for automation due to a mix of different activities (e.g., management, consulting, physical work, data collection and analysis). Among these, between 40 and 90% are related to physical work. This includes some functions that are not currently expected to become automated (e.g., large-scale sowing or harvest of certain products, phytosanitary treatments) and some that are predicted to become or already are automated (McKinsey Global Institute, 2017). Regarding the latter, the livestock sector has been able to fully automate milking activity for 30 yr, thanks to the development and diffusion of automatic milking systems (**AMS**).

The interest of the livestock sector in automation and precision technologies is constantly expanding (Cogato et al., 2021); some worldwide companies are already producing automation technology as well as pursuing continued innovation and patent production (Sharipov et al., 2021). The potential to overcome the difficulty in finding skilled labor, the reduction of the heavy workload of milking, and the increase of milking events that do not rely on human labor and the incurred additional labor costs can be identified as the key drivers of AMS adoption for dairy farmers (Jacobs and Siegford, 2012b). In 2020, AMS manufacturers estimated about 50,000 units were already in operation worldwide (Simões Filho et al., 2020), and by 2025, 50% of dairy farms in northwestern Europe are expected to be equipped with AMS (Hansen et al., 2019). The reasons for this success are based not only on the possibility of automating a repetitive physical function and improving working conditions (Stræte et al., 2017), making

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the working day more flexible and manageable, but also on increasing animal welfare and optimizing human-animal interactions (Wildridge et al., 2020), leading to positive effects on milk production. No less important are the health-related aspects, considering that milking tasks represent a very strenuous occupational activity (Masci et al., 2020). Finally, the economic evaluation of investments and the energy demands are very important; both are aspects that depend on many factors and are strongly influenced by farm management (Calcante et al., 2016; Matei et al., 2020).

Along with the increasing adoption of robotic milking, many studies were carried out to analyze the consequences of robotic milking on milk yield and quality (Speroni et al., 2006; Lessire et al., 2020; Masía et al., 2020); animal behavior, health, and welfare (Dohmen et al., 2010; Piwczyński et al., 2020), herd management (Penry et al., 2018; Tse et al., 2018b), and labor efficiency (Karttunen et al., 2016; Hansen and Stræte, 2020). Schewe and Stuart (2015) observed that the adoption of AMS changed the operations and organization of dairy farms, reshaping the relationships among farmers, animals, technology, and the environment. However, the authors highlighted that the implications of automatic milking were not experienced uniformly. They varied depending on the context, leading to a diversity of outcomes and effects.

Despite the growing interest recorded for robotic milking over the past few years in Northern and Central Italy, a survey aimed to assess technical-productive aspects of dairy farms equipped with AMS that operate in different contexts is missing from this region to the best of our knowledge. Our objective focused on using typification and characterization of farms in Northern and Central Italy through multivariate statistical methodologies to provide technical information both to farmers and technicians already adopting AMS, and to those potentially interested in robotic milking.

MATERIALS AND METHODS

Data Collection

The study involved 62 dairy farms, mostly located in Piemonte, Lombardia, Emilia-Romagna, Veneto, Trentino-Alto Adige, Friuli Venezia-Giulia (Northern Italy), and to a lesser extent, Lazio and Umbria (Central Italy). Altogether, these regions contribute to over 88% of Italian milk production (CLAL, 2020).

Farms were characterized by adopting AMS of the same manufacturer (Lely, Maassluis, the Netherlands), although they were different models in relation to the installation year and in different numbers depending on the herd size. Lely (~760 units installed in 2019) covered more than 60% of the Italian market, which overall numbered about 1,200 AMS units (personal communication, Lely Italia). For pragmatic reasons (i.e., time constraints and project manageability), farms were selected through convenience sampling; inclusion criteria were that farmers had to have adopted robotic milking for at least 1 yr and be able to provide their farm data. Overall, the 62 farms involved in the survey represented about 10% of all the farms that adopted automatic milking in Italy in 2019, whereas the AMS overall installed in these farms accounted for about 12.5% (149) of the milking robots installed (personal communication, Lely Italia).

A questionnaire was designed to collect quantitative and qualitative data from farms participating in the survey to evaluate their technical-productive aspects. A set of 36 questions, organized in 7 sections, were defined to obtain a general description of farm features and overall management practices (Table 1). The sections of the questionnaire were as follows: (a) farm characteristics, (b) buildings and facilities, (c) milk production, (d) milk quality, (e) feeding, (f) reproduction, and (g) veterinary costs.

Daily number of cows milked/AMS, daily milk production (kg/cow), and daily milk yield/AMS (kg) were extracted from the Lely T4C (Time-for-Cows) management software and averaged over 1 yr. Milk production/year and milk production at 305 d were estimated from the daily milk production (kg/cow) averaged over 1 yr, considering a time span of 365 d and an average dry period of 60 d. Increased milk production after the AMS installation was calculated by comparing the average annual milk productions obtained respectively with the AMS in the first year of operation and with the conventional milking system during the previous year, as declared by farmers. Data related to milk quality [percentage of protein and fat, total bacterial count (**TBC**), SCC] were obtained from the report analysis delivered weekly by dairy factories to farmers and were averaged over 1 yr. The feeding cost (€/kg of milk) was estimated from the cost of the ration administered daily to each cow (€/cow), as declared by farmers, and the daily milk production (kg/cow), both averaged over 1 yr. Veterinary costs (€/cow) were calculated by dividing the total veterinarian fees that were incurred by farmers for visiting and treating animals (including the cost of drugs) over 1 yr by the number of lactating cows. All other farm data were provided by farmers through on-farm interviews. The reference period for the data was the year 2019, except for the increased milk production, which referred to the AMS installation date.

The questionnaire was printed, and the survey was carried out from January to February in 2020 thanks

Table 1. Questionnaire designed to collect data from farms participating in the survey (January–February 2020, Italy)

Section	Question	Notes
(a) Farm characteristics		
	1. Geographical area (N, C, S&I)	n = North; C = Central; S&I = South and Isles
	2. Region	
	3. Land availability (ha)	Cultivated land area
	4. Breed (F, O)	F = Friesian; O = others breeds
	5. Lactating cows (n)	
	6. Milk production/year (t)	
	7. AMS installed (n)	AMS = automatic milking system
	8. Type of AMS installed	Astronaut model: A2, A3, A4, A5
	9. Cows/AMS (n)	Cows managed by one AMS
	10. Previous milking system (P, MP)	P = pipeline; MP = milking parlor
	11. FTE (n)	FTE = full-time employee
	12. Yearly milk production/FTE (t)	
(b) Buildings and facilities		
	13. Housing (S, B)	S = stalls; B = bedding
	14. Stalls (n)	
	15. Cows/stall (n)	
	16. Barn (EB, NB, E&NB)	EB = existing barn; NB = new barn; E&NB = existing and new barn
	17. Ventilation system (Y, N)	Y = yes, N = no
	18. Water spraying system (Y, N)	Y = yes, N = no
(c) Milk production		
	19. Daily milk production (kg/cow)	
	20. Milk production at 305 d (kg/cow)	
	21. Daily milk yield/AMS (kg)	
	22. Increased milk production after AMS installation (%)	
(d) Milk quality		
	23. Protein (%)	
	24. Fat (%)	
	25. TBC (cfu/mL)	TBC = total bacterial count
	26. SCC (cells/mL)	
(e) Feeding		
	27. Ration base (S, H)	S = silage; H = hay
	28. Feeding cost/kg of milk (€/kg)	
	29. Automatic feed pusher (Y, N)	Y = yes, N = no
	30. Concentrate-feeder (Y, N)	Y = yes, N = no
(f) Reproduction		
	31. Lactations (n)	
	32. Age at first delivery (mo)	
	33. Services per conception (n)	
	34. Calving-conception interval (d)	
	35. Yearly culled cows (%)	
(g) Veterinary costs		
	36. Veterinary costs (€/cow)	Veterinary visits, treatments, drugs

to the collaboration with the manufacturer. Questionnaires were filled in during face-to-face interviews with the farmers. Respondents were the owners of the farms, and they were given the option to answer or skip any question as well as to stop the survey at any point. All producers responded to all questions, with the exception of 4 farms that did not have information on veterinary costs. Data extracted from the management software and provided by farmers were recorded anonymously. None of the human subjects involved in the survey could be identified directly or through identifiers linked to the subject. Because the main topic of the research was to collect data related to AMS and the research did not focus on human subjects, human material, human tissue, or human data, neither data collection processed pursuant to regulation 2016/679 (European Union, 2016) nor authorization from the Ethics or data protection point of view were deemed to be necessary by the Ethics Committee of Università degli Studi di Milano (Italy).

Data Processing

Data collected through the questionnaires were digitalized by the components of the research team using a spreadsheet (Excel, Microsoft Corp.). These data, along with those extracted from the T4C management software, were then exported to JMP Pro 15.2 (SAS Institute) for the principal component analysis (**PCA**) and successive cluster analysis (**CA**; Ding and He, 2004).

The final data set included the responses of all 62 dairy farms involved in the survey. The number of

Table 2. General characteristics, buildings, and facilities for each group of dairy farms obtained in the cluster analysis; frequency, mean, and SD are reported where applicable (reference year: 2019, Italy)

Variable	Cluster 1 (n = 24)	Cluster 2 (n = 31)	Cluster 3 (n = 7)
Geographical area (%)			
North Italy	83	100	100
Central Italy	17	0	0
Region (%)			
Piemonte	8	29	0.0
Lombardia	21	55	72
Veneto	25	10	14
Friuli-Venezia Giulia	17	0	0
Trentino-Alto Adige	4	3	0
Emilia-Romagna	8	3	14
Lazio	13	0	0
Umbria	4	0	0
Land availability (ha)	51 ± 28[b]	83 ± 45[b]	316 ± 148[a]
Breed (%)			
Friesian	63	100	100
Other breeds	37	0	0
Lactating cows (n)	80 ± 32[b]	98 ± 34[b]	441 ± 118[a]
Milk production/year (t)	900 ± 393[b]	1,307 ± 489[b]	6,124 ± 1.789[a]
Automatic milking system (AMS) installed (n)	1–3 (2 ± 1)[b]	1–3 (2 ± 1)[b]	5–13 (8 ± 3)[a]
Type of AMS installed (%)			
A2	0	0	14
A3	16	26	12
A4	81	72	62
A5	3	2	12
Number of cows/AMS (n)	52 ± 10[b]	58 ± 8[a]	54 ± 7[a,b]
Previous milking system (%)			
Pipeline	17	13	0
Milking parlor	83	87	100
Full-time employee (FTE) (n)	2 ± 1[b]	1 ± 1[b]	5 ± 1[a]
Annual milk production/FTE (t)	620 ± 193[c]	1,031 ± 329[b]	1,335 ± 243[a]
Housing (%)			
Stalls	87	87	100
Bedding	13	13	0
Stalls (n)	92 ± 39[b]	104 ± 36[b]	464 ± 181[a]
Cows/stall (n)	0.9 ± 0.1	1.0 ± 0.2	1.0 ± 0.3
Barn (%)			
Existing barn	71	74	0
New barn	29	26	0
Existing barn + new barn	0	0	100
Ventilation system (%)	83	90	100
Water spraying system (%)	4	19	57

[a–c]Values in the same row with different superscripts differ significantly ($P < 0.05$).

answers for all questions was the same except for the question related to veterinary costs, where 4 farmers did not answer because they did not have data.

Statistical Analysis

The PCA was carried out using the following quantitative variables (Table 1): lactating cows (n), AMS installed (n), daily milk production (kg/cow), full-time employee (**FTE**; n), yearly milk production/FTE (t), increased milk production after AMS installation (%), and daily milk yield/AMS (kg). The PCA converts a set of variables, throughout an orthogonal transformation, into new linearly uncorrelated variables called principal components (**PC**). The PC with eigenvalues greater than 1 (Kaiser's rule; Kaiser, 1960) were retained and used for *k*-means CA, which allowed for allocation of the dairy farms into 3 groups. To improve characterization and typology of each cluster's groups, the other quantitative and qualitative variables reported in Table 1 were added to the original selected quantitative variables. Statistical differences ($P < 0.05$) between clusters were assessed with regards to the quantitative variables by a one-way ANOVA with Tukey–Kramer mean comparison and, with regards to the qualitative variables, a Pearson chi-squared test of contingency tables.

Table 3. Milk production and milk quality for each group of dairy farms obtained in the cluster analysis; frequency, mean, and SD are reported where applicable (reference year: 2019, Italy)

Variable	Cluster 1 (n = 24)	Cluster 2 (n = 31)	Cluster 3 (n = 7)
Daily milk production (kg/cow)	31 ± 3^b	37 ± 3^a	38 ± 2^a
Milk production at 305 d (kg/cow)	$9,303 \pm 791^b$	$11,132 \pm 948^a$	$11,560 \pm 537^a$
Daily milk yield/automatic milking system (AMS; kg)	$1,571 \pm 283^b$	$2,113 \pm 335^a$	$2,054 \pm 273^a$
Increased milk production after AMS installation (%)	14 ± 7	16 ± 10	12 ± 3
Protein (%)	3.4 ± 0.2	3.3 ± 0.1	3.3 ± 0.1
Fat (%)	3.8 ± 0.2	3.7 ± 0.2	3.8 ± 0.1
Total bacterial count (cfu/mL × 1,000)	8.9 ± 4.4	8.5 ± 3.7	12.5 ± 9.3
SCC (cells/mL × 1,000)	185.2 ± 53.3	199.8 ± 44.4	191.2 ± 43.4

[a,b]Values in the same row with different superscripts differ significantly ($P < 0.05$).

RESULTS

Two PC were selected (eigenvalues greater than 1), representing 71% of the total original variance. The distribution of farms according to the *k*-means CA showed that 24 farms were in cluster 1 "small-to-medium-sized farms with low productivity," 31 farms in cluster 2 "small-to-medium-sized farms with high productivity," and 7 farms in cluster 3 "large-sized farms with high productivity." The mean values of qualitative and quantitative variables for each typology group of farms are reported in Tables 2, 3, and 4.

Cluster 1: "Small-to-Medium-Sized Farms with Low Productivity"

This cluster included 24 farms that milked between 38 and 150 cows, using 1 to 3 AMS. These farms were characterized by an average annual milk production of 900 ± 393 t (mean ± SD) and an average land availability of 51 ± 28 ha (Table 2). Most of them (83%) were in Northern Italy, mainly in Veneto (25%) and Lombardia (21%). The most common type of dairy cow raised was the Holstein-Friesian, although 37.5% of farms raised Italian Brown and Italian Red Pied cows. Most of the AMS (82%) were installed after 2010; in those farms that milked with a pipeline system (17%), the transition from conventional to automatic milking led to the adoption of the loose-housing system in substitution of the tiestall system. Loose housing on deep litter was limited to 13% of cases, whereas 87% of the farms housed cows in freestalls. On average, the stall stocking density (**SSD**), measured as the number of lactating cows per stall in a freestall barn, was 93% (0.93 cows per freestall). The average number of FTE was 2 ± 1 with an annual milk yield of 620 ± 193 t/FTE. In 29% of farms, the adoption of the milking robot required the construction of a new barn, whereas in the remaining cases (70.8%) the existing structures were suitably adapted. Most of the farms (84%) had ventilation systems to mitigate cow heat stress, whereas water cooling systems were adopted only in 4% of the structures (Table 2). In this group of farms, on average, 31 ± 3 kg of milk/cow per day or 9,302 ± 791 kg of milk/cow over 305 d were obtained, with an average increase in milk yield of 14% after the introduction of milking robots. Farmers harvested, on average, 1,571 ± 283 kg of milk/robot per day, milking 52 ± 10 cows per robot. Regarding milk quality, protein and fat contents were 3.4 ± 0.2% and 3.8 ± 0.2%, respectively. The TBC was 8,900 ± 4,400 cfu/mL and the SCC was 185,200 ± 53,300 cells/mL (Table 3). Dairy cows received a partial mixed ration (**PMR**) mainly based on corn silage in 78.3% of farms, with an average feeding cost of 0.21 ± 0.05 €/kg of milk produced. Feed was pushed up with an automatic pusher and self-feeders were installed, respectively, in 17% and 13% of farms (Table 4). Regarding the average reproductive performance, the age at first calving was 26 ± 3 mo, the calving-conception interval was 120 ± 27 d, and services/pregnancy were 2.2 ± 0.5. The average lactation number was 3.2 ± 0.9, and the average culling rate was 30 ± 10%. Finally, the average veterinary costs were 49.60 ± 32.16 €/cow (Table 4).

Cluster 2: "Small-to-Medium-Sized Farms with High Productivity"

The second cluster analyzed included 31 farms, all located in Northern Italy, in Lombardia (55%), Piemonte (29%), and Veneto (10%). These farms milked 48 to 180 Holstein-Friesian cows with an average annual milk production of 1,307 ± 489 t, and they had an average farmland availability of 83 ± 45 ha (Table 2). As in cluster 1, most of the AMS (74%) were installed after 2010, and their number ranged between 1 and 3, according to the number of milking cows. Before installing AMS,

Table 4. Feeding, reproduction, and veterinary costs for each group of dairy farms obtained in the cluster analysis; frequency, mean, and SD are reported where applicable (reference year: 2019, Italy)

Variable	Cluster 1 (n = 24)	Cluster 2 (n = 31)	Cluster 3 (n = 7)
Ration base (%)			
Hay	22	10	0
Silage	78	90	100
Feeding cost (€/kg milk)	0.21 ± 0.05[a]	0.17 ± 0.02[b]	0.19 ± 0.02[ab]
Automatic feed pusher (%)	17	10	57
Self-feeder (%)	13	3	14
Lactations (n)	3.2 ± 0.9[a]	2.7 ± 0.6[b]	2.6 ± 0.3[a,b]
Age at first calving (mo)	26 ± 3	25 ± 2	24 ± 1
Services per conception (n)	2.2 ± 0.5[b]	2.4 ± 0.4[a,b]	2.9 ± 0.7[a]
Calving-conception interval (d)	120 ± 27	126 ± 23	136 ± 20
Culling rate (%)	30 ± 10	26 ± 7	30 ± 9
Veterinary costs (€/cow)	49.60 ± 32.16[b]	97.62 ± 59.01[a]	112.29 ± 50.64[1]

[a,b]Values in the same row with different superscripts differ significantly ($P < 0.05$).

[1]Value calculated on 3 farms.

most of the farms (88%) used a milking parlor, whereas a minority (13%) used a pipeline milking system. As observed in cluster 1, the transition to automatic milking in farms with a pipeline milking system coincided with the adoption of the loose housing in substitution of a tiestall system. Relating to housing, 13% of the farms used deep litter, and 87% used freestall systems. On average, the SSD was 97% (0.97 cows per freestall). The average number of FTE was 1 ± 1 with an annual milk yield of 1,031 ± 243 t/FTE. In 26% of farms, the adoption of robotic milking required a new barn, whereas the old barns were adapted in the remaining 74% of farms. Most of the farms (90%) were equipped with ventilation systems to mitigate cow heat stress, and about one-fifth of them (19%) had water cooling systems for cooling dairy cows at feed line (Table 2). On average, 37 ± 3 kg of milk/cow per day or 11,132 ± 948 kg of milk/cow over 305 d were obtained, with an average increase in milk yield of 16% after the adoption of robotic milking. Milking, on average, 58 ± 8 cows/AMS, farmers harvested an average of 2,113 ± 335 kg of milk/robot per day with the following qualitative characteristics: protein (3.3 ± 0.1%), fat (3.7 ± 0.2%), TBC (8,500 ± 3,700 cfu/mL), SCC (199,800 ± 44,400 cell/mL; Table 3). Dairy cows received a PMR mainly based on corn silage in 90.3% of farms, with an average feeding cost of 0.17 ± 0.02 €/kg of milk produced. Only a low percentage of farms pushed up feed with an automatic pusher (9.7%) and installed self-feeders (3.2%; Table 4). On average, the age at first calving was 25 ± 2 mo, the calving-conception interval was 126 ± 23 d, and services/pregnancy were equal to 2.4 ± 0.4. The average lactation number was 2.7 ± 0.6, and the average culling rate was 26.3 ± 7.3%. Finally, the average veterinary costs were 97.62 ± 59.01 €/cow (Table 4).

Cluster 3: "Large-Sized Farms with High Milk Production"

The last cluster consisted of 7 large farms, located in Lombardia (72%), Veneto (14%), and Emilia-Romagna (14%), with an average annual milk production of 6,124 ± 1,789 t and an average land availability of 316 ± 148 ha (Table 2). These farms milked 240 to 620 Holstein-Friesian cows using 5 to 13 AMS. In these farms, the milking robots were installed gradually over time following the numerical growth of the herd between 2009 and 2019. Cows were housed both in new and existing freestall barns with an average SSD of 101% (1.01 cows per freestall). All the farms were equipped with ventilation systems to mitigate cow heat stress, whereas water cooling systems for cooling dairy cows at feed line were installed in 4 farms (57% of the total in cluster 3). The average number of FTE was 5 with an annual milk production of 1,335 ± 243 t/FTE (Table 2). In this cluster, an average of 38 ± 2 kg of milk/cow per day or 11,560 ± 537 kg of milk/cow over 305 d were obtained with an average increase in milk yield of 12% after the introduction of milking robots. Milking 54 ± 7 cows per AMS, farmers harvested 2,054 ± 273 kg of milk/robot with the following qualitative characteristics: protein (3.3 ± 0.1%), fat (3.8 ± 0.1%), TBC (12,500 ± 9,300 cfu/mL), SCC (191,200 ± 43,400 cell/mL; Table 3). Dairy cows received a PMR completely based on silages, with an average feeding cost of 0.19 ± 0.02 €/kg of milk produced. The automatic feed pusher was present in 4 farms (57% of total), whereas concentrate-feeders were only present in 1 farm (Table 4). On average, the age at first calving was 24 ± 1 mo, the calving-conception interval was 136 ± 20 d, and services/pregnancy were 2.9 ± 0.7. The average lactation number was 2.6 ± 0.3, and the average culling rate was 30 ± 9% (Table 4). Finally, veterinary costs were 112.29 ± 50.64 €/cow (Table 4).

DISCUSSION

In this study, a set of quantitative and qualitative variables were used to characterize a sample of 62 dairy farms equipped with AMS and located in Northern and Central Italy. Combining PCA and k-means CA allowed partitioning the farms in 3 groups, reducing the variance among farms of the same cluster and maximizing the variance between clusters.

Most of the cows reared in the surveyed farms belonged to the Holstein-Friesian breed, and fewer cows belonged to the Italian Brown and Italian Red Pied breeds. This is in line with the national statistics for the dairy cattle population, where Holstein is the main breed reared in Italy with over than 1 million heads, followed by Italian Brown and Italian Red Pied with about 70,000 and 60,000 heads, respectively (AIA, 2018). Overall, the average lactation yield per cow recorded in surveyed farms rearing Holstein-Friesian was comparable with the official statistics (AIA, 2018), whereas it was higher than the official statistics in farms rearing Italian Brown and Italian Red Pied. However, a comparison between farm data and official data is difficult for these breeds because automatic milking is less common than in Holstein cows.

Cluster 1 mostly represented small-to-medium dairy farms with low productivity, mainly located in the Northeast Italy (Lombardia, Veneto, Friuli-Venezia Giulia). These farms were characterized by low AMS loading and low daily milk yield per cow. The AMS were not fully used and the efficiency and productivity of the manpower could be improved. Farmers of cluster 1 perceived the AMS as a means to improve quality of life. As reported in literature, most farmers who switched to automatic milking experienced greater job satisfaction, better work conditions (Hansen, 2015; Woodford et al., 2015; Tse et al., 2018b), more flexibility in schedule and activities, improved family and social life (De Koning, 2010; Molfino et al., 2014), and reduced physical workload (Meskens et al., 2001).

Clusters 2 and 3 included dairy farms with high productivity of small-to-medium-sized herds, located mainly in Northwest Italy (Lombardia and Piemonte), and of large herds, located mainly in Lombardia, respectively. These farms, regardless of size, were characterized by a higher AMS loading and milk production when compared with dairy farms belonging to cluster 1. For farmers of clusters 2 and 3, the introduction of automatic milking represented a change in the way farms were managed. The effects of this change can be summarized as less overall labor (Mathijs, 2004; Bijl et al., 2007; Rodenburg, 2017), reduced labor costs (Jago and Burke, 2010), and increased work productivity (Karttunen et al., 2016).

In all of the farms, regardless of the cluster they belonged to, the main milk quality and reproductive parameters were consistent with the national average data reported by the Italian Breeder Association (AIA, 2018). The annual milk production was not significantly different between clusters 1 and 2, whereas cluster 3 differed compared with clusters 1 and 2 (Table 2). The data analysis highlighted a difference in terms of efficiency between clusters 1 and 2. Farms of cluster 2, which milked on average only 18% more heads than farms of cluster 1, produced an amount of milk 30% higher than the amount produced on an annual basis by farms of cluster 1. This could be because a third of the farms belonging to cluster 1 raised Italian Brown and Italian Red Pied cows, which have a lower annual milk production than Holstein-Friesian cows (ANAPRI, 2019; ANARB, 2019; ANAFI, 2019).

The average daily milk production of cows housed in cluster 1 farms was significantly lower ($P < 0.05$) by 16% and 20% compared to clusters 2 and 3, respectively. An explanation could be related to microclimatic control of barns; only 4% of farms from cluster 1 used water cooling systems at feed line, which, in combination with fans, allow the body temperature to be lowered by evaporation. This value rose to 19% and 57% in clusters 2 and 3, respectively (Table 2). Dairy cows cooled by fans associated with water cooling systems produce more milk than cows cooled only with forced ventilation (Broucek et al., 2020). The average lower daily milk production, together with the average lower AMS loading of farms belonging to cluster 1 (51.5 cows/AMS), explained why milking robot productivity was 26% and 24% lower in these farms compared with what was recorded in farms of clusters 2 and 3, respectively (Table 3). Tremblay et al. (2016), analyzing data from 635 North American dairy farms equipped with AMS, report average daily production of 1,626.80 ± 396.99 kg of milk/AMS, with 50.50 ± 9.54 cows producing 31.98 ± 4.91 kg of milk/cow. A study carried out in Spain on 34 herds (Castro et al., 2012) reports similar values, with a main daily production of 1,463 kg of milk from 52.7 cows that produce an average of 28 kg of milk/day. The AMS manufacturers suggest that about 2,000 kg of milk/day from 60 cows producing on average 33 kg of milk/day can be considered a reasonable target for a single AMS station (Rodenburg, 2017). In all 3 clusters, the introduction of AMS led to a milk production increase ranging between 12% and 16% (Table 3). Although the first year after installation could be considered an adaptation year, both per cows and farmers, we believed these values consistent. A study carried out by Tse et al. (2018b) showed that producers took 1 wk to train cows or heifers to adapt to the AMS, and the average time for an entire herd to adapt was 30 d. In other studies where cows were trained (Jacobs and Siegford, 2012a) or not trained (Spolders et al., 2004), it was reported that it took a similar average of 7 to 8 d for a cow to adapt to an AMS. Jacobs and Siegford (2012a), in a study aimed to determine the duration of time required for cows to adapt to milking in an AMS, compared milk yields of cows milked in the conventional milking parlor and in the AMS. Milk yield 4 d after the transition to the AMS exceeded the average attained 4 d before transitioning to robotic milking. The observed milk production increase may be a consequence of the direct relationship between milking frequency and milk secretion as demonstrated by many researchers (Hillerton et al., 1990; Knight et al., 1992; Klei et al., 1997; Stelwagen 2001; Løvendahl and Chagunda 2011; Bonora et al., 2018) who reported 6 to 28% higher milk production when increasing milking frequency. Moreover, in accordance with the switch to automatic milking, most farmers chose to build new freestall barns and improve their facilities. In a study carried out on AMS herds, Deming et al. (2013) found that cows had greater milk yield when provided with more space (m/cow) at the feed bunk, likely encountering fewer aggressive interactions with other animals and having the chance to increase DMI (DeVries and von Keyserlingk, 2006). More space at the feed bunk is also positively associated with greater lying duration (Deming et al., 2013). Dairy cattle are highly motivated to lie down for approximately 12 h/d (Drissler et al., 2005; Fregonesi et al., 2007; Gomez and Cook, 2010), and a positive relationship between milk yield and resting time was observed by Grant (2007), who estimated a milk response of approximately 3.7 pounds for every additional hour of resting time a cow achieves.

The number of FTE in cluster 3 was significantly higher ($P < 0.05$) than the other 2 clusters due to the higher number of lactating cows and AMS installed (Table 2). In cluster 3, a single FTE produced 115% and 30% more milk annually than clusters 1 and 2, respectively. This is consistent with the findings of Hadley et al. (2002), where increasing herd sizes resulted in improved labor efficiency due to several factors such as labor-saving technology adoption, skilled and managerial personnel employment, better facilities use, and economies of size (Bewley et al., 2001; O'Brien et al., 2007).

A large quota of farms belonging to cluster 1 (29.2%) and cluster 2 (25.8%) built new barns when switching from conventional to automatic milking because cows were previously housed in tiestall systems and milked with a pipeline milking system. On the other hand, in large farms (cluster 3), the simultaneous presence of existing structures, suitably adapted, and new barns was considered to be a consequence of the progressive increase in number of cows and, consequently, in AMS units over time (Table 2). Loose housing on deep litter was limited to smaller farms of clusters 1 and 2 (on average 58.3 cows and 1 AMS for cluster 1; 90.8 cows and 2 AMS for cluster 2), whereas all the other farms were characterized by freestall barns. No statistical difference was observed in SSD between clusters and the number of lactating cows per stall in freestall barns (ranging between 0.93 ± 0.13 in cluster 1 and 1.01 ± 0.30 in cluster 3; Table 2).

Cluster 3 showed higher milk bacterial count, more services per conception, and a wider calving-conception interval compared with clusters 1 and 2 (Tables 3 and 4). This could be due to the high number of cows managed by a single FTE in cluster 3 (96 cows/FTE), which may decrease the individual attention toward dairy cows. Bijl et al. (2007) reported that Dutch farms using AMS had an average of 74 cows/FTE. This value is comparable to what we observed in cluster 2 (75 cows/FTE) but higher compared with cluster 1 (53), where the less intensive nature of the farms (lower number of cows/FTE, lower AMS loading, and production level) prevailed. This aspect could explain the lower veterinary costs (i.e., visits, treatments, drugs) recorded in farms belonging to cluster 1, considering that veterinary costs are influenced by herd size and milk production level (Hoerning et al., 2005). The type of breeds raised can also determine the level of health costs on a farm; it is widely accepted that local breeds are more robust than Holstein-Friesian and can be considered a high maintenance animal for use in extremely standardized intensive systems (Van Diepen et al., 2007; Rodríguez-Bermúdez et al., 2019). In cluster 1, a large quota of farms (37.5%) raised Italian Brown and Italian Red Pied cows, and this could lead to fewer veterinary treatments (Mastrangelo et al., 2018).

The values of the main milk qualitative (Table 3) and reproductive parameters (Table 4) are comparable between farms belonging to the different clusters and consistent with the national average data reported by the Italian Breeders Association (AIA, 2018). The TBC of milk produced by farms is well below the legal limit (100,000 cfu/mL) and the number of somatic cells is below the limit required to produce of high-quality milk (300,000 cells/mL), highlighting correct herd management. Cluster 3 was characterized by a relatively low average number of lactations per cow (2.6 ± 0.3). Although this value agreed with the average value of intensive dairy farms in Northern Italy (2.4 lactations/cow, AIA, 2018), it should be highlighted that this management choice does not seem optimal, considering that the highest milk yield is usually attained in third-lactation cows (Vijayakumar et al., 2017). The higher average number of lactations (3.2) recorded in cluster 1, on the other hand, seems to confirm the less intensive approach of these farms.

Overall, typification and characterization of AMS farms through multivariate statistical methodologies allow dairy farmers potentially interested in robotic milking to evaluate different scenarios of development of their activities. In this way, dairy farmers can decide whether to adopt an AMS to increase cows' quality of life, rather than to achieve better production performance. On the other hand, farmers already adopting robotic milking and falling in a specific cluster could evaluate whether they are reaching their objectives or whether a change in farm management is required. Farm advisors play a pivotal role supporting farmers in their technical, economic, organizational, or social decisions, providing them with expert knowledge (Dockès et al., 2019). Clustering could be used by farm advisors to identify customer needs and to plan a possible intervention adaptively for a larger pool of farms instead of following each one individually.

Limitations of the present survey included the potential for misinterpretation of questions, recall bias, interviewer bias, and social desirability bias, similar to what is reported by Tse et al. (2018a) in a study aimed to determine producers' reports of change in milking labor management, milk production, milk quality, and participation in dairy herd improvement programs after adopting automatic milking. The misinterpretation of questions that leads respondents to answer a different question than was intended was minimized by keeping our questions short and simple. The recall bias that occurs when participants in a survey do not remember previous events or data accurately was minimized by allowing farmers to skip questions if they could not remember details. The interviewer bias was minimized by reading each question exactly as it appeared without interpreting the question for the respondent and repeating the question exactly as it appeared if requested. The social desirability bias that can be understood as a respondent's tendency to bias their responses in surveys to appear in a more favorable light (Crowne and Marlowe, 1960) was minimized by explaining to the participants that the survey was anonymous. People report lower social desirability when they are anonymous (Joinson, 1999).

CONCLUSIONS

The combination of PCA and k-means CA is a powerful assessment tool for the a posteriori characterization of farming systems. Among the 62 Northern and Central Italian dairy farms equipped with AMS and covered by the survey carried out in this study, 3 clusters were identified. Cluster 1 mostly represented small-to-medium-sized dairy farms with low productivity, mainly located in the Northeast Italy, in which the AMS was likely perceived as a means to improve quality of life. Clusters 2 and 3, respectively, included dairy farms with high productivity of small-to-medium size, located mainly in Northwest Italy, and of large size, located mainly in Lombardia. In these farms, regardless of size, the introduction of automatic milking represented the way to reach higher productive performance. This characterization of farms could help dairy technicians give farmers customized management advice by function of the cluster they belong to. On the other hand, farmers falling in a specific cluster could evaluate whether they are reaching their objectives.

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