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Automatic Milking in Greece: First Insight into Udder Health of Dairy Cows

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ABSTRACT: Udder health is a key factor for dairy cows' productivity and welfare. This study presents the first insight into dairy cows' udder health after the introduction of automatic milking systems in Greece. Four farms with Holstein dairy cows and automatic milking systems enrolled in the study. Data from their milking records were utilized, from January 2020to December 2021.Variables employed in the assessment were cow daily milk yield (DMY), number of daily milkings / cow, individual cow somatic cell count (SCC), proportion of cows with elevated somatic cell count (ELSCC) / month, proportion of cows with chronically ELSCC (ChrELSCC) / month and number of new ELSCC (NewELSCC)cases per 100 cows / month. Two years' mean milking frequency was 2.72milkings / cow / day, ranged from 2.47 to 2.98, and decreased from 2020 to 2021. Mean cow SCC was 193,000 cells/mL, ranged from 70,000 to 260,000 cells/mL, and increased from 2020 to 2021.Meancow DMY was 37.2kg, ranged from 29.6 to 43.6 kg. Heifers had lower mean SCC than cows and mean SCC increased from early to late lactation stages. On a monthly basis, 37.06% and 40.06% of the cows were ELSCC in 2020 and 2021, respectively, and most of them were chronic. The highest ELSCC was observed in late lactation stage. Fresh cows presented the highest number of New ELSCC / 100 cows / month, both years of the study. Overall udder health in the four automatic milking farms of this study was better than conventional farms in Greece. Precision dairy farming should utilize daily milking data for data-driven management, monitoring of chronically ELSCC, and early detection, treatment and prevention of new infections.

Keywords: automatic milking, robotic milking, udder health, somatic cell count, dairy cows, Greece.

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INTRODUCTION

Automatic milking is an important step towards precision dairy farming and is increasingly adopted by dairy farmers. The first commercially available automatic milking systems (AMS) were introduced in the Netherlands in 1992. By 2017, around 38000 AMS had been installed, mostly in dairy farms of Western Europe and North America (Hallen Sandgren and Emanuelson, 2017). The global milking robots market worth was estimated at USD 1.25 billion in 2019 and is expected to reach USD 2.94 billion by 2027 (Fortune Business Insights report, 2019). The first AMS in a Greek dairy farm was deployed in 2016. By the end of 2021, the total number of cattle dairy farms converted to AMS has reached 21.

Milking procedure consumes about 25% to 35% of the annual labor time in conventional milking systems (de Koning, 2010). Reduction of time spent on repetitive manual tasks, difficulties regarding the availability and cost of competent labor force and the need for higher productive efficiency with lower inputs lead to an increasing demand for automatic milking. AMS could increase milk production by up to 12% and decrease labor by up to 18% (Jacobs and Siegford, 2012). A single AMS unit typically services 50 to 70 animals. Multiple units are used to service larger herds. To achieve optimal efficiency an AMS unit should be occupied approximately 80% of a 24-hour period for milking (Penry et al., 2018). Hitherto, AMS are mostly used in indoor housing systems, but there is an increasing interest for the integration of AMS into pasture-based systems (John et al., 2016). In Greece, all AMS were installed in farms with indoor housing systems.

Conversion from conventional to automatic milking, also referred to as robotic milking, comes with several challenges for herd health and farm management. Factors related to the environment, cow, and milking could affect udder health (Lievaart et al., 2007). Several studies reported deterioration of udder health, milk quality and decrease in milk yield after the conversion (Klungel et al., 2000; Rasmussen et al., 2001; Kruip etal., 2002; De Koning, 2004; Mulder et al., 2004; Poelarends et al., 2004; Rasmussen, 2006).Over the first year after the introduction of AMS, Hovinen et al. (2009) recorded an increase in mean cow somatic cell count (SCC) and proportion of new high-SCC cows, especially during a two to three months' adaptation period. Rasmussen et al. (2001) recorded a sudden increase in new elevated SCC cows, simultaneously with the conversion to robotic milking and a slow decrease after 3 months. Proportion of new elevated-SCC cows among cows at risk remained high throughout the first year, but also four years after the introduction of AMS (Rasmussen, 2006).

Poor udder health before the introduction to robotic milking leads to lower chances of having good udder health after the conversion (Neijenhuis et al., 2010). Regarding Greek dairy farms with conventional milking, in a four-year retrospective study, Themistokleous et al. (2019) recorded poor udder health. One in three cows had elevated SCC, with most of the new infections occurring in the first 60 days in milk and a high proportion of heifers with elevated SCC. Due to these findings and the reported deterioration of udder health after the conversion to robotic milking, we conducted the first investigation of dairy cows' udder health in Greek farms with AMS.

This study aims to present the first insight into udder health of dairy cows in four Greek farms with automatic milking systems, throughout a two-year period. Utilizing daily milking data from the AMS, our study presents individual cow somaticcell count, daily milk yield per cow, daily milking frequency per cow, proportion of cows with elevated SCC (new and chronic), regarding herd, lactation period and lactation stage groups, during 2020 - 2021.

MATERIALS AND METHODS

Farms' profile

Four farms with Holstein dairy cows and automatic milking systems participated voluntarily in the present study, from the 1st of January 2020 until the 31st of December 2021. Mean herd size was 186 (±30) cows, with a mean of 156 (±25) milking cows, serviced by 2 to 3 robotic arms, accordingly, installed in respective number of milking barns with free flow cow traffic. Each robotic arm serviced a mean of 62 (±5) cows. The robot types installed in the farms were Lely Astronaut A4 and Lely Astronaut A5 Automatic Milking Systems (Lely HoldingB.V., Maassluis, the Netherlands). All cows were fed a partial mixed ration and extra concentrates were fed according to their milk yield at the automatic milking system. Milking cows were housed in free-stall barns. Rubber mattress beds were used, cleaned once or twice a day. Number of stalls per barn was sufficient, with 76 to 93% of the stalls occupied. Manure removal from the barn floor was carried out by automatic scrapers at least 3 to 4 times a day. The area around the robot was cleaned by workers once or twice a day.

Different dry-off and dry cow therapy protocols were applied from farm to farm. Blanket dry cow therapy without teat sealants was applied in three farms, while selective dry cow therapy with blanket use of teat sealants was applied in the fourth farm. Udder hair was not trimmed or singed, and tails were not trimmed, although it is a standard procedure for robotic milking. Cows were visually inspected in the barn at least twice a day by the farmers. Udder health related notifications were checked once or twice a day. Monthly clinical mastitis cases varied from one to five, according to the farmers. Percentage of three-quarter cows varied from 1 to 6%of the milked cows. Number of cows culled due to mastitis varied from 0 to 3.Only one of the farms had milk samples' bacteriological analysis results from high SCC or mastitis cows, during the last year. None of the farms had separate milking facility for treated/sick/fresh cows.

Datasets and data analysis

In the present retrospective study, data related to udder health and milk quality derived from milking records during the study period. On a daily basis, individual cow milk data from the robotic milking systems were stored in Lely T4C database (Lely Holding B.V., Maassluis, the Netherlands). In total, 275,025 daily milking recordings were utilized. The variables obtained from each daily milking recording for each cow were cow ID and date of recording, lactation period, days in milk (DIM), daily milk yield (DMY), number of milkings / cow / day, and a mean number of SCC from all milkings /cow / day.

Udder health metrics were calculated from raw data. These metrics included monthly proportion of elevated SCC cows (ELSCC), monthly proportion of chronically elevated SCC cows (ChrELSCC) and number of new elevated SCC (New ELSCC) cases per 100 cows per month. A cow was recorded as ELSCC when the mean daily SCC was >150,000 cells/mL for at least two successive days within a month. ELSCC cows for ≥2 successive months were recorded as ChrELSCC. New ELSCC were cows recorded as ELSCC on a certain month that were not ELSCC during the previous month. Monthly proportions and yearly mean proportions of ELSCC, ChrELSCC and NewELSCC cows were calculated for herd, lactation period and lactation stage groups.

Data analysis involved herd, lactation period and lactation stage groups. Lactation period groups included "heifers" (1st lactation) and "cows" (≥2nd lactation). Lactation stage included "fresh" (5-30 DIM), "early lactation" (31-100 DIM), "mid-lactation" (101-200 DIM), "late lactation" (201-305 DIM) and "prolonged lactation" (>305 DIM). For each farm, Pearson correlation analysis was performed on daily recordings between DMY, number of daily milkings / cow and individual cow SCC in SPSS (IBM Corp. Released 2020. IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY: IBM Corp). Udder health metrics' mathematical formulas were transformed in Python functions, applied on each farm's dataset, using Python programming language (Python Software Foundation, https://www.python.org/). Microsoft Excel® (MicrosoftCorporation. Microsoft Office 365, Retrieved from https://it.auth.gr/el/cloudServices/office365) was used for the presentation of the results.

RESULTS

Daily Milk Yield and Milking Frequency

In 2021, mean cow 305-days milk yield was 10,522 kg, 10,095 kg, 12,383 kg and 11,956 kg in farms A, B, C and D, respectively. Four farms' two-years' mean cow DMY was 37.2 kg, ranged from 29.6 to 43.6 kg, and decreased from 2020 to 2021. Number of fetch cows reported by the farmers was 0 to 1 in farms A, C and D, but 10 in farm B. In farm B mean cow daily milk yield increased from 2020 to 2021, in farms C and D it remained the same and in Farm A it decreased, at herd, cows' and heifers' groups. Four farms' two-years' mean milking frequency was 2.72 milkings / cow / day, ranged from 2.47 to 2.98, and decreased from 2020 to 2021.Regarding lactation stage groups, milking frequency increased between fresh and early lactation, slightly decreased in mid-lactation and decreased in late lactation and prolonged lactation stages. These results are presented in Table 1.Pearson correlation coefficients ($p < 0.001$) between daily cow recordings of DMY and number of daily milkings per cow for 2020 and 2021, respectively, were 0.468 and 0.534 in Farm A, 0.526 and 0.398 in Farm B, 0.138 and 0.225 in Farm C and 0.428 and 0.471 in Farm D.

Somatic Cell Count

Four farms' two-years' mean cow SCC was 193,000 cells/mL, ranged from 70,000 to 260,000 cells/mL, and increased from 2020 to 2021.At herd level, mean individual cow SCC of farms A, C and D was approximately three times higher than farm B, both years of this study. There was an increase in mean cow SCC of farms A and C from 2020 to 2021, while farms B and D remained the same. Both years, heifers had a lower mean SCC than cows in farms A, C and D, but higher in Farm B. Fresh cows in farms A, C and D had higher mean individual SCC than farm B, both in 2020 and 2021. Two-years' mean SCC gradually increased from early to late lactation, in farms A, C and D. In late lactation, mean SCC in farms A, C and D was four times higher than farm B. In farm C, two-years' mean individual SCC at prolonged lactation was twice as high as early lactation. These results are presented in Table 1.Pearson correlation coefficients ($p < 0.001$) between daily cow recordings of DMY and individual cow SCC for 2020 and 2021, respectively, were -0.122 and -0.179 in Farm A, -0.128 and -0.162 in Farm B, -0.179 and -0.149 in Farm C and -0.075 and -0.126 in Farm D.

Table 1*:* Milking descriptive statistics of the four farms enrolled in the study, during 2020 and 2021

		2020						2021						Mean 2020-2021		
Farm		Milkings /cow / day	± SD	DMY (kg)	± SD	SCC (x1000 cells / mL)	± SD	Milkings /cow / day	± SD	DMY (kg)	± SD	SCC (x1000 cells / mL)	± SD	Milkings /cow / day	DMY (kg)	SCC (x1000 cells / mL)
A	*Herd*	2.91	0.75	37.2	8.3	184	374	2.77	0.73	34.1	7.9	243	488	2.84	35.7	214
	Heifers	2.90	0.93	31.5	7.2	149	305	2.78	0.86	26.8	6.6	200	388	2.84	29.2	174
	Cows	2.94	0.92	37.8	10.4	236	454	2.77	0.91	34.4	10.7	272	545	2.86	36.1	254
	Fresh	2.56	0.82	33.5	11.1	150	345	2.99	0.77	35.2	10.9	170	425	2.77	34.4	160
	Early	2.94	0.76	39.5	8.9	131	311	3.03	0.77	38.3	10.2	170	425	2.98	38.9	151
	Mid	3.04	0.71	36.4	7.4	189	396	2.85	0.72	34.3	8.7	240	529	2.94	35.3	215
	Late	3.03	0.68	31.6	6.6	232	418	2.73	0.63	30.3	7.5	255	523	2.88	30.9	244
	Prolonged	2.73	0.71	26.9	7.7	187	333	2.58	0.69	24.9	7.6	297	468	2.65	25.9	242
B	*Herd*	2.64	0.65	29.6	7.8	70	206	2.47	0.55	31.6	7.7	70	216	2.56	30.6	70
	Heifers	2.62	0.57	27.5	6.0	90	258	2.37	0.48	28.6	5.1	83	255	2.49	28.0	86
	Cows	2.67	0.70	31.4	8.6	53	146	2.54	0.58	33.7	8.5	62	184	2.60	32.5	57
	Fresh	2.77	0.69	32.6	7.3	67	259	2.52	0.57	33.1	8.1	69	213	2.65	32.9	68
	Early	2.96	0.68	35.8	6.9	71	258	2.62	0.58	35.9	8.7	55	219	2.79	35.8	63
	Mid	2.73	0.59	31.6	6.8	90	258	2.51	0.53	33.3	7.3	76	261	2.62	32.4	83
	Late	2.47	0.60	26.9	6.2	55	119	2.44	0.53	29.9	6.0	65	159	2.45	28.4	60
	Prolonged	2.44	0.56	24.3	6.1	61	106	2.28	0.49	26.0	5.4	86	204	2.36	25.2	74
C	*Herd*	2.98	0.77	39.0	10.3	203	422	2.77	0.74	38.9	11.0	259	460	2.87	38.9	231
	Heifers	2.94	0.76	36.4	7.7	117	193	2.61	0.60	35.4	7.7	176	378	2.77	35.9	147
	Cows	3.01	0.77	41.2	11.7	273	533	2.88	0.80	41.3	12.3	317	501	2.94	41.2	295
	Fresh	2.97	0.90	39.8	10.9	125	297	2.83	0.77	38.6	11.8	162	352	2.90	39.2	143
	Early	3.06	0.80	46.3	9.5	135	345	2.89	0.83	45.7	10.9	166	386	2.97	46.0	151
	Mid	3.15	0.66	42.3	7.2	188	410	2.91	0.69	42.7	8.7	268	489	3.03	42.5	228
	Late	3.03	0.70	36.0	7.0	225	442	2.76	0.67	35.4	8.0	329	510	2.90	35.7	277
	Prolonged	2.50	0.72	27.9	8.2	337	529	2.33	0.60	28.4	8.3	312	422	2.42	28.1	324
D	*Herd*	2.69	0.80	43.5	10.6	253	544	2.54	0.77	43.6	10.2	260	498	2.61	43.5	256
	Heifers	2.81	0.86	35.0	8.1	122	282	2.60	0.78	34.9	7.5	173	333	2.70	34.9	147
	Cows	2.62	0.76	40.3	12.2	326	634	2.48	0.77	40.9	11.8	336	596	2.55	40.6	331
	Fresh	2.63	0.81	39.8	12.3	240	494	2.52	0.83	39.4	12.6	273	554	2.57	39.6	256
	Early	2.84	0.80	45.6	10.7	258	578	2.70	0.76	44.0	10.5	216	450	2.77	44.8	237
	Mid	2.82	0.78	41.3	8.3	290	638	2.69	0.76	40.3	8.3	248	495	2.76	40.8	269
	Late	2.64	0.81	34.1	8.6	225	481	2.35	0.71	33.1	7.5	313	532	2.50	33.6	269
	Prolonged	2.36	0.70	27.6	8.5	212	341	2.23	0.69	29.1	7.2	232	394	2.29	28.3	222

On a yearly basis, four farms' mean number of milkings / cow / day, mean daily milk yield per cow (DMY - kg), mean cow somatic cell count (SCC) (x1000 cells / mL). These descriptive statistics refer to herd, lactation period groups ["heifers": 1st lactation period, "cows": ≥2nd lactation period] and lactation stage groups ["fresh": 5 -30 days in milk (DIM), "early": 31-100 DIM, "mid": 101-200 DIM, "late": 201-305 DIM, "prolonged": >305 DIM]. Two-years' mean milking descriptive statistics are presented ("Mean2020-2021").

Elevated Somatic Cell Count, Chronic and New

Udder health metrics, presented in Table 2, followed similar trends as individual SCC. From 2020 to 2021, farms A and C had an increase in the proportion of ELSCC cows, while farms B and D had a decrease. In 2021, in farms A, C and D, half of the animals presented an elevation of mean daily SCCfor ≥2 successive days at some point within a month, and one out of three remained ChrELSCC. On a monthly basis, 11 out of 100 animals were NewELSCC in 2021. In the same year, proportion of ChrELSCC in farms A, C and D was approximately 6 times higher than farm B. All farms presented an increase in New-ELSCC from 2020 to 2021.

In farm B heifers had higher ELSCC and ChrELSCC than cows, both in 2020 and 2021. Half of these ELSCC heifers were chronic. In the same farm, heifers had higher NewELSCC than cows in 2021. A deterioration of udder health metrics was observed in farms A and C, regarding lactation period groups. In farm A, 2020, one third of heifers was ELSCC and one fourth was ChrELSCC, with an increase in 2021. Heifers' NewELSCC increased from 2020 to 2021, almost reaching cows' NewELSCC in 2021. In farm C, heifers' NewELSCC increased from 2020 to 2021, surpassing cows' NewELSCC in the second year of the study. In farm D, 63.30% of the cows presented elevated SCC for ≥2 successive days in 2020. Most of these cows were ChrELSCC (Table 2).

Fresh cows had the highest NewELSCC among all lactation stages' groups, in all farms, both years of the study. A decrease in the proportion of ELSCC was observed from fresh to early lactation but increased from mid-lactation to late lactation. An increase in NewELSCC was observed from mid to late lactation, in 2021. In the same year, one in four fresh cows started her lactation period with ELSCC. A high proportion of ChrELSCC in late and prolonged lactation stages was recorded in farms A, C and D. In farm B, an improvement of udder health metrics was recorded in most of the lactation stage groups from 2020 to 2021 (Table 2).

Table 2: Udder health metrics of the four farms enrolled in the study, during 2020 and 2021

2020

	Farm A			Farm B			Farm C			Farm D			Mean 2020		
	ELSCC	Chronic ELSCC	new ELSCC	ELSCC	Chronic ELSCC	new ELSCC	ELSCC	Chronic ELSCC	new ELSCC	ELSCC	Chronic ELSCC	new ELSCC	ELSCC	Chronic ELSCC	new ELSCC
Herd	38.85%	26.18%	13	16.39%	9.36%	5	40.31%	27.61%	13	52.68%	42.51%	9	37.06%	26.42%	10
Heifers	33.78%	22.64%	11	17.52%	10.45%	5	27.39%	17.94%	9	29.42%	20.90%	7	27.03%	17.98%	8
Cows	44.00%	30.37%	15	14.73%	8.01%	5	49.31%	33.80%	15	63.30%	52.99%	10	42.83%	31.29%	11
Fresh	26.23%	4.56%	21	21.61%	9.09%	10	22.56%	3.59%	19	24.62%	4.77%	20	23.75%	5.50%	17
Early	20.73%	9.97%	11	13.43%	7.65%	6	20.11%	8.26%	11	18.05%	12.56%	6	18.08%	9.61%	9
Mid	30.69%	17.09%	16	17.40%	9.75%	7	34.11%	18.64%	16	24.63%	18.06%	6	26.71%	15.88%	12
Late	29.29%	16.17%	16	11.93%	6.42%	5	50.64%	35.36%	16	26.89%	19.80%	7	29.69%	19.44%	11
Prolonged	28.60%	14.79%	14	14.47%	7.45%	4	37.99%	24.01%	13	23.62%	18.34%	6	26.17%	16.15%	9

2021

	Farm A			Farm B			Farm C			Farm D			Mean 2021		
	ELSCC	Chronic ELSCC	new ELSCC	ELSCC	Chronic ELSCC	new ELSCC	ELSCC	Chronic ELSCC	new ELSCC	ELSCC	Chronic ELSCC	new ELSCC	ELSCC	Chronic ELSCC	new ELSCC
Herd	47.96%	33.79%	14	12.02%	5.55%	7	51.36%	37.48%	14	48.89%	39.07%	10	40.06%	28.97%	11
Heifers	44.14%	34.28%	14	13.88%	6.92%	8	36.39%	21.21%	15	32.75%	24.17%	9	31.79%	21.65%	11
Cows	46.18%	31.68%	15	10.49%	4.47%	6	59.97%	47.69%	12	56.37%	46.32%	10	43.25%	32.54%	11
Fresh	26.47%	4.32%	23	11.00%	2.41%	10	35.52%	5.73%	29	23.57%	3.92%	20	24.14%	4.10%	21
Early	28.03%	11.58%	17	6.90%	1.94%	6	28.21%	14.97%	13	16.94%	11.16%	6	20.02%	9.92%	10
Mid	40.41%	21.78%	19	10.60%	5.31%	6	45.54%	27.38%	18	24.35%	17.62%	7	30.23%	18.02%	12
Late	46.05%	26.25%	20	12.48%	4.28%	8	60.81%	40.35%	20	31.46%	24.56%	7	37.70%	23.86%	14
Prolonged	50.49%	37.81%	13	11.99%	4.54%	8	44.62%	29.67%	15	30.28%	23.02%	7	34.34%	23.76%	11

Yearly mean proportion of cows with mean daily somatic cell counts >150,000 cells/mL for at least two successive days within a month, called elevated somatic cell count cows (ELSCC). Yearly mean proportion of ELSCC cows for two or more successive months, called chronically ELSCC cows (ChrELSCC). Yearly mean number of ELSCC cows on a cer-tain month that were not ELSCC during the previous month, called new ELSCC cows (NewELSCC) per 100 lactating cows per month. These metrics refer to herd, lacta-tion period groups ["heifers": 1st lactation period, "cows": ≥2nd lac-tation period] and lactation stage groups ["fresh": 5 -30 days in milk (DIM), "early": 31-100 DIM, "mid": 101-200 DIM, "late": 201-305 DIM, "prolonged": >305 DIM].Four farms' yearly mean udder health metrics are presented ("Mean 2020", "Mean 2021").

DISCUSSION

In 2016, the first AMS was installed in a Greek dairy farm. Ever since, many dairy farms have converted to robotic milking, making AMS one of the main investment trends in cattle dairy farms of Greece. According to Hovinen and Pyörälä (2011) udder health of dairy cows milked automatically not only had not improved, but, on the contrary, certain problems appeared after the transition from conventional to robotic milking. Neijenhuis et al. (2010) supported that herds with poor udder health before the conversion to AMS were less likely to have good udder health after this change. In a four-year study of dairy farms with conventional milking systems in Greece, Themistokleous et al. (2019) reported poor udder health, affecting cows' productive longevity and milk quality. These facts underlined the necessity of an investigation of udder health traits in Greek dairy farms with AMS.

Udder health and traits of cow productivity in the four robotic farms enrolled in this study were better than farms with conventional milking systems reported by Themistokleous et al. (2019). In 2021, mean cow 305-days milk yield in these AMS farms was 17% (1,631 kg) higher than conventional farms in 2018. Two-years' mean DMY of all four farms of our study was higher than mean DMY found by Kruip et al. (2002) and Castro et al. (2012), while three of the four farms had higher DMY than mean milk yield in Tse et al. (2018) (Table 1). Two-years' mean daily milkings / cow in the four farms varied from 2.56 to 2.87 (Table 1), considered good in comparison with similar studies (Pettersson et al., 2011; Castro et al., 2012; Tse et al. 2018). Increased milking frequency in AMS is expected to have a positive impact on DMY (de Koning, 2004; Pettersson et al., 2011; Hart et al., 2013; Hogenboom et al., 2019).

The DMY - milkings / cow / day correlation coefficients ($p < 0.001$) showed a positive relationship between DMY and number of daily milkings per cow in all four farms, both 2020 and 2021. Siewert et al. (2018) analyzed longitudinal AMS daily data and found a positive association between DMY per AMS and milking frequency. Higher milking frequency leads to shorter milking intervals, which, in turn, are related to higher milk production per cow per hour (Hogeveen et al., 2001). Shorter milking intervals due to more frequent milking and better overall management of the four AMS farms of our study could have contributed to higher milk yields. However, the decrease observed in milking frequency from 2020 to 2021 could be a matter of concern that needs further evaluation.

Mean SCC of herd, lactation period and lactation stage groups, presented in Table 1, was lower than the somatic cell scores' equivalent of the respective groups in conventional farms (Themistokleous et al., 2019). In three of the four farms mean cow SCC increased at herd level from 2020 to 2021. A SCC increase from early to late lactation was recorded in these farms, both years of the study. This fact, along with the wide standard deviations of mean SCC are indicative of a dispersion among individual cows' mean SCC, which possibly means that numerous cows had elevated mean SCC for long periods, in agreement with the proportions of ELSCC and ChrELSCC presented in the paragraphs below.

Within 24 months after the conversion to AMS, Tse et al. (2018) found that bulk tank SCC increased in 24% of the farms, decreased in 42% and stayed the same in 35% of them. Mean bulk tank SCC in the same study was 188,000 cells/mL. Rasmussen et al. (2001) found an increase in mean SCC the first year after the introduction of AMS and a somatic cell score of 5.28, which is worse than the results of the four Greek AMS farms. In a Czech study, Janštová et al. (2011) found a mean SCC of 221,000 cells/mL. Kruip et al. (2002) supported that SCC were significantly increased in AMS farms and that this is potentially a matter of concern. Klungel et al. (2000) and de Koning (2004) reported slightly higher SCC in automatic milking compared to conventional farms. The latter found a mean SCC of 190,000 cells/mL, almost equal to the four Greek AMS farms' mean.

The DMY - SCC correlation coefficients ($p < 0.001$) showed a negative relationship between DMY and individual cow SCC in all four farms, both 2020 and 2021. Higher SCC leads to loss in milk yield and, thus, lower production efficiency (Philpot, 1984). Cows with high SCC produce a lower milk volume than cows with low SCC and there is a negative correlation between total milk volume produced and SCC of milk. Intramammary infections may reduce milk yield through chronic damage to mammary secretory cells, but even in short-duration infections with no permanent damage, metabolic resources may be diverted from milk production to immune defense (Green et al., 2006). In our study, the increase in mean SCC observed in three of the four farms from 2020 to 2021 implies a necessity for further evaluation of this situation. Data-driven management and farm-specific interventions need to be applied to prevent deterioration.

Metrics of udder health in Greek AMS farms, are presented in Table 2. Proportion of ELSCC cows was high, both at herd level and among lactation groups (heifers and cows). The majority of those cows were ChrELSCC. Number of NewELSCC cows was high in the fresh cows' stage and both in cows' and heifers' groups. Mean proportion of ELSCC cows in three of the four AMS farms, presented in Table 2, was higher than the mean of conventional farms presented by Themistokleous et al. (2019). In the present study, the cut-off value for a cow to be classified as ELSCC was 150,000 cells/mL, instead of 250,000 cells/mL used in Themistokleous et al. (2019). Also, daily milking data from the robots provide a more sensitive method, compared to the once-a-month sampling method in conventional farms, partially explaining this result.

Hovinen et al. (2009) reported a higher proportion of cows at risk for elevated SCC in herds with AMS and an increase in the proportion of ELSCC cows. Rasmussen et al. (2001) observed a sudden and significant increase in newly elevated SCC cows during the first year of automatic milking, more new infections than conventional milking systems and an overall ELSCC proportion of 39.3% after the conversion to AMS. This result is very similar to the four farms' mean proportion of ELSCC, 2020 and 2021, presented in Table 2.

In both studies of robotic and conventional systems in Greece the highest NewELSCC appeared in the fresh cows' group, indicating similar problems in the dry period and calving management.High number of new cases among fresh cows, might have been due to inadequate conditions and management of the dry period and calving. These problems also reflected on the increasing proportion of ELSCC and ChrELSCC during successive lactation stages, leading to a climax in late and prolonged lactation. A similar build-up trend of these metrics during successive lactation stages was observed between robotic and conventional systems. The lack of proper protocols for early detection and prevention of new cases of elevated SCC might have led to chronic udder health problems and the deterioration of udder health in late lactation.

CONCLUSIONS AND RECOMMENDATIONS

Udder health in the four automatic milking farms of this study was better than conventional farms in Greece (Themistokleous et al., 2019). Two-years' mean cow somatic cell count was 193,000 cells/mL, lower than conventional farms, mean cow daily milk yield was 37.2 kg and milking frequency was 2.72 milkings / cow / day. However, the decrease in the number of daily milkings per cow and the increase in SCC, from 2020 to 2021, is a matter of concern. Proportion of elevated SCC cows was high, and most of these cows appeared to have a chronic problem. Udder health metrics appeared problematic since the 1st lactation period (heifers). Fresh cows had the highest number of new elevated SCC cases per 100 cows per month.

AMS dairy farmers in Greece should focus on more effective utilization of daily milking data, monitoring of chronic cases, early detection and treatment of subclinical mastitis. Management of the dry period and calving should be optimized. The reduction of SCC and improvement of udder health could lead to higher milk yields, better milk quality and optimal efficiency of the automatic milking systems.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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