Austral Journal of Veterinary Sciences

Austral J Vet Sci 57, e5704 (2025)
https://doi.org/10.4206/ajvs.57.04

ORIGINAL ARTICLE

Perception of Chilean dairy farmers facing the growing heat stress events in the country

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Article History
Received: 07.10.2024
Accepted: 10.01.2025
Published: 14.04.2025

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ABSTRACT. Global warming is one of the major problems worldwide that dairy farmers will have to cope with in the coming decades. Dairy cattle can cope with adverse weather conditions by modifying their physiological and behavioral mechanisms to maintain their body temperature within a normal range, but this can affect their performance and welfare. This study aimed to determine the perception of Chilean dairy farmers regarding the phenomena of heat stress. A survey was submitted by email to dairy farmers from different dairy production regions. Dairy producers from 28 communes in Chile answered the survey, covering almost all of the country's dairy production regions. Most dairy farmers had more than 500 animals, with a predominantly grazing production system and all-year-round calving. The average milk yield was 7,226 L/cow/lactation, with the majority (85%) of the dairy farmers stating that they had some knowledge or ideas about what heat stress is, but only 46% stated that they know how it affects animals. Likewise, 91.6% were open to receiving training on this matter, and 88% were willing to have an app for cell phones, allowing them to monitor the risk of heat stress and provide suggestions to mitigate its impact on their production system. In conclusion, dairy farmers are worried about the effects of heat stress on their businesses and are willing to receive training and practical tools regarding heat stress in dairy cattle.

Keywords: Heatwave, animal welfare, milk yield, thermal index, farmer knowledge.

INTRODUCTION

Heat stress is one of the biggest challenges faced by dairy farmers worldwide (Carabaño *et al*., 2016; Polsky & von Keyserlingk, 2017). Nevertheless, few studies have addressed the perceptions of dairy farmers regarding this topic. Many climate models predict changes in the global climate because of an increase in atmospheric carbon dioxide (CO_2) concentration, which causes temperature increases and changes in the distribution of precipitation (Konapala *et al*., 2020). Estimates of increases in the global mean surface temperature range up to 5 °C above the pre-industrial level (Arnell *et al*., 2019). The influence of climate on cattle has been studied for a long time (Gengler *et al*., 1970; Johnson *et al*., 1962). The physiology, behavior, and health of livestock are markedly influenced by the environment in which they live, which can significantly affect their productive and reproductive performance (Gaughan *et al*., 2019; Sejian *et al*., 2018).

In dairy cattle, heat stress occurs when the ambient temperature exceeds the animals' thermal comfort zone and they are unable to dissipate enough heat to maintain homeothermy (West, 1999). The thermoneutral zone for dairy cows is between 4 and 24 °C (Hahn, 1981), which is regularly exceeded in many parts of the world. Heat stress occurs because of excess heat produced internally or by exposure to high ambient temperatures (Bernabucci *et al*., 2014; Kadzere *et al*., 2002). Cattle are homeothermic animals, that is, organisms that, despite fluctuations in environmental temperature, can maintain a relatively constant body temperature (Shephard & Maloney, 2023). When cows are exposed to conditions exceeding the thermoneutral zone, their fertility, productivity, health status, and general welfare are negatively affected (Nardone *et al*., 2010; Tao *et al*., 2020), thereby, decreasing their milk quality and production.

According to Kadzere *et al*. (2002), the thermoregulatory ability of modern cows has received less attention. Greater milk yields require greater feed consumption and metabolic activity, which, in turn, produces a greater heat load. Therefore, modern specialized dairy cows have become less heat-resistant and consequently more susceptible to heat stress. The capacity of livestock to face adverse weather conditions, particularly a combination of ambient temperature, relative humidity, wind speed, and solar radiation, is variable and influenced by the species, breed, age, color of the coat and skin, length of the coat, and nutritional level, among others factors (Arias, 2006).

In regions where heat stress problems are frequent worldwide, an emergency plan is recommended, with various actions that reduce the negative impact of the climate on cattle. These plans include monitoring and early detection, cooling strategies, water and nutritional management, animal handling, and shade access (Ji *et al*., 2020).

During the last decade, Chile has experienced increasing trends in heat waves, especially in the central regions of the country (Piticar, 2018). Heat waves are defined as a period in which daily maximum temperatures exceed a threshold, equivalent to the 90th percentile of the daily maximum temperature distribution for the climatological reference period 1991-2020, for three or more consecutive days. The most extreme case was recorded in 2017 in Curicó City, with a heat wave lasting 16 continuous days (Dirección Meteorológica de Chile 2024; Vicencio, 2018). In addition, an increase in temperature is projected for the country, which would go from high to low in the direction from north to south and from the mountain range to the ocean. In the most favorable scenario for 2030, the increase in temperature would fluctuate between 0.5°C for the southern zone and 1.5°C for the northern zone and highlands of the country (Ministerio del Medio Ambiente, 2024). For the period between 2031 and 2050, according to these projections, the warming pattern is maintained but with higher values that would reach up to 2.0°C in the northern zone.

A similar trend has been observed in countries such as the United States and Australia, where heat stress is a recurring problem of great importance. Thornton *et al*. (2009) reported that the incidence of days under heat stress conditions in Australia increased significantly (~60%), as well as a substantial increase (138%) in the frequency of heat stress incidence. In South America, both Brazil and Argentina have addressed heat stress (Carvalho *et al*., 1995; Gallardo *et al*., 2005; Valtorta *et al*., 1999) by focusing on dairy cattle and their thermoregulatory responses. Additionally, some studies have been conducted on dairy producers' perceptions of heat stress (Brettas *et al*., 2024).

In Chile, there is scarce information regarding the effect of climatic conditions on the productive responses of cattle, particularly dairy cattle. Mansilla (1996) evaluated the effect of maximum temperature, minimum temperature, and relative humidity on the day of insemination on the reproductive efficiency of dairy cows in the Biobio region and reported that heat stress caused a notable decrease in the fertility of cows. Subsequently, from 2010 onwards, most of the research on this subject has been done by our team, conducting various studies in the central and southern areas of Chile (Arias *et al*., 2021; Arias *et al*., 2018; Arias & Mader 2010; Jara *et al*., 2016; Soto *et al*., 2018). Farmers' perceptions regarding heat stress have been addressed in different countries, such as Australia, Brazil, Sweden, South Africa, and the USA (Cardoso *et al*., 2018; Diniso *et al*., 2022; Hendricks *et al*., 2022; Lane *et al*., 2019; Tamminen *et al*., 2024). However, to date, no research has addressed the perception of Chilean dairy farmers regarding heat stress in dairy cows or the future challenges associated with it. Therefore, our objectives were 1) to characterize Chilean dairy farmers, determining the relevance of heat stress for them, 2) to estimate the knowledge of dairy farmers in terms of understanding heat stress as well as mitigation strategies, and 3) to determine their willingness to receive training and use tools, such as a smartphone app.

MATERIAL AND METHODS

Survey design and validation

A survey was designed to collect information on dairy farms in three dimensions: 1) general information to characterize the dairy farms (location, farmer age, number of cows at the dairy farm, dairy system (grazing, confinement or mixed), calving distribution, estimated milk yield by lactation, and predominant breed) (seven questions); 2) heat stress knowledge, including questions about heat stress, thermal comfort indices, identification of an animal under heat stress conditions, weather variables affecting animal thermal balance, climate change, effects of heat stress on animals, and mitigation strategies (12 questions); and 3) training demand and willingness to have practical tools to cope with heat stress (five questions). The survey consisted of 24 questions divided into three sections designed to gather comprehensive information on thermal stress knowledge. It included six open-ended questions to capture qualitative insights, 13 single-selection questions for focused responses, one multiple-selection question to explore broader preferences, and four rating scale questions (Strongly disagree; Disagree; Neutral; Agree; Strongly agree) to evaluate specific aspects quantitatively.

The survey was conducted using a web platform (https://www.questionpro.com/) that was previously validated with a subgroup of 15 dairy farmers from a group that had previously worked with the university and were willing to do so. This process consisted of a timeframe in which farmers had access to the questionnaire, after which they submitted all the doubts that required clarification. Subsequently, the team included the corresponding modifications to the questionnaire which was distributed to dairy farmers via email between October 2022 and January 2023. The database for the distribution of the survey was obtained from the Chilean Dairy Consortium, DeLaval S.A., Chilean Dairy Federation (FEDELECHE), and the Association of Farmers of Valdivia (APROVAL AG), totaling 630 dairy farmers who could potentially participate.

Chilean dairy production regions

Given the geographical characteristics of the country, there is great variation in climate types, agroecosystems, and dairy production systems. Therefore, the Chilean dairy consortium divided the country into eight dairy production regions (DPR) (Table 1). For instance, confinement systems are mainly located in Central Chile (DPR I and II), whereas grazing systems are found in southern regions (DPR III to VIII). There is also great variability in cattle genetics access to the market and feedstuffs, among many other characteristics. Lanuza *et al*., (2013) provided a detailed explanation of Chilean DPRs.

Statistical analysis

The analysis included the average milk yield per lactation and the average age of dairy farmers for better characterization as response variables. On the other hand, the production system, farm size, and DPR were used as study factors. The statistical analysis included descriptive as well as ANOVA and Chi-square tests, with a level of significance of 5%. Each dairy farmer was considered as an observational unit. All analyses were performed using the JAMOVI statistical package (Version 2.3.26.0).

RESULTS

Of 630 potential dairy farmers, 362 accessed the survey website (57.5% of the total database). However, only 85 (13.5%) dairy farmers answered the questionnaire, with an average response time of seven minutes. Responders represented a total of 28 communes in Chile, covering practically all Chilean dairy production regions (Table 1). The geopolitical regions with a higher percentage of participants were Los Ríos (44%) and Los Lagos (40%), followed by La Araucanía and Ñuble (4% each) and Maule (2.7%). Meanwhile, the Metropolitan, O'Higgins, Valparaíso, and Biobío regions represented 1.33% of the total.

At the communal level, the highest proportions of participants were Río Bueno (11.8%), Paillaco and Purranque (7.1% each), and La Unión and Río Negro (5.9% each). Overall, these five communes represented 37.65% of the total responses. The second group of communes, which represented 18.8% of the total, included Frutillar, Los Muermos, Osorno, and Valdivia (each with 4.7%). The third group of communes, including Los Lagos, Máfil, Panguipulli, and Puerto Octay, represented 14.12% of the surveys. Finally, the commune of Victoria had a representation of 2.35%, and the remaining 15.3% corresponded to the communes of Bulnes, Casablanca, Chillán, Chimbarongo, Coihueco, Curepto, Lanco, Los Ángeles, Melipilla, Puyehue, Renaico, San Pablo, and Teno. There was an 11.8% of dairy farmers that did not register their communes.

Characterization of Dairy farms and farmers

The average age of the dairy farmers was 46.9 years ± 1.51 (standard error of the mean), ranging between 23 and 75 years. No differences were observed in the age of dairy farmers depending on farm size ($P = 0.583$), dairy production system ($P = 0.132$) (Figure 1a), or DPR (Figure 1b). A lower variability in the ages of dairy farmers was observed in those with confinement production systems. Of the total respondents, dairy farms with more than 500 heads were predom-

Table 1.
Distribution of Chilean Dairy production regions (DPR) according to political regions and communes.

DPR	Chilean political region	Communes
I	Metropolitan - Valparaíso	Casablanca, Melipilla, María Pinto, Padre Hurtado, and Pirque
	O'Higgins	Rancagua, Rengo, San Fernando
	Maule	Curicó, Talca, Linares
II	Bio-Bio - Ñuble	Los Ángeles, Chillán, Concepción
	La Araucanía	Angol - Renaico
III	La Araucanía (Central Plains)	Victoria, Lautaro, Vilcún, Temuco, Freire, Pitrufquén, Gorbea, and Loncoche
IV	Los Ríos (Central Plains)	Lanco, Máfil, Los Lagos, Paillaco, and Río Bueno
V	Los Lagos (Central Plains)	Osorno, Purranque, and Casma
VI	Los Lagos (South and west plain, north Chiloé Island)	Los Muermos, Maullín, Puerto Montt, and Ancud
VII	La Araucanía, Los Ríos, and Los Lagos (Andes range)	Villarica, Panguipulli, Futrono, Lago Ranco, Puyehue, Rupanco, and Pueto Octay
VIII	Los Ríos y Los Lagos (coastal range)	La Unión, Costa Osorno, Río Negro, Crucero, Purranque, and Fresia

Notes; Based on Lanuza *et al*., 2013

inant (42.3%), followed by dairy farms with 301 to 500 heads and between 151 and 300 heads (17.3% and 21.2%, respectively), those farms between 51 and 150 heads reached 13.5%, and dairy farms with less than 50 heads represented 5.8% of respondents. No differences in milk yield were observed according to farm size (Table 2) ($P = 0.467$).

Grazing dairy farms were predominant ($P < 0.001$), reaching 52.5% of the participants, followed by mixed dairy farms (35.6%), and confined systems (11.9%). No differences in milk production were observed among dairy production systems ($P = 0.242$) (Figure 2a). An important proportion of dairy farmers (43%) indicated that they had a distribution of calving throughout the year, while only 21% indicated that they had spring calving, and 36% stated that they had a bi-seasonal calving distribution (autumn-spring).

The average milk yield was 7,226 L/cow per lactation, with a median of 7,000 L/cow per lactation. Most of the surveyed dairy farmers (81.58%) declared having milk yields ranging from 5,000 to 10,000, followed by those with less than 5,000 (10.53%), and only 7.89% stated milk yield production > 10,000. The minimum range was 4,200 in Puerto Octay and a maximum of 15,000 in Curepto. The highest milk yield production was reported in the central zone (DPRs I and II), specifically in the regions of Valparaíso, Metropolitan, and Maule with 12,505, 12,300, and 10,550 L/cow per lactation, respectively, but no differences were observed ($P = 0.654$) (Figure 2b). The Los Lagos and Los Ríos regions averaged 7,184 and 6,657 L/cow per lactation, respectively. When milk yield was analyzed according to farm size, no differences were observed ($P = 0.467$) (Table 2).

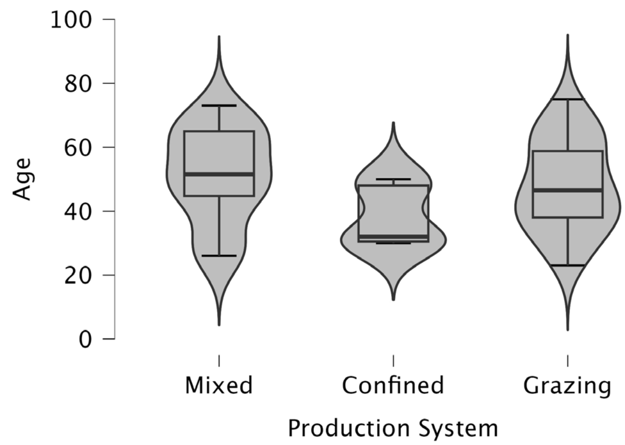

Figure 1a.

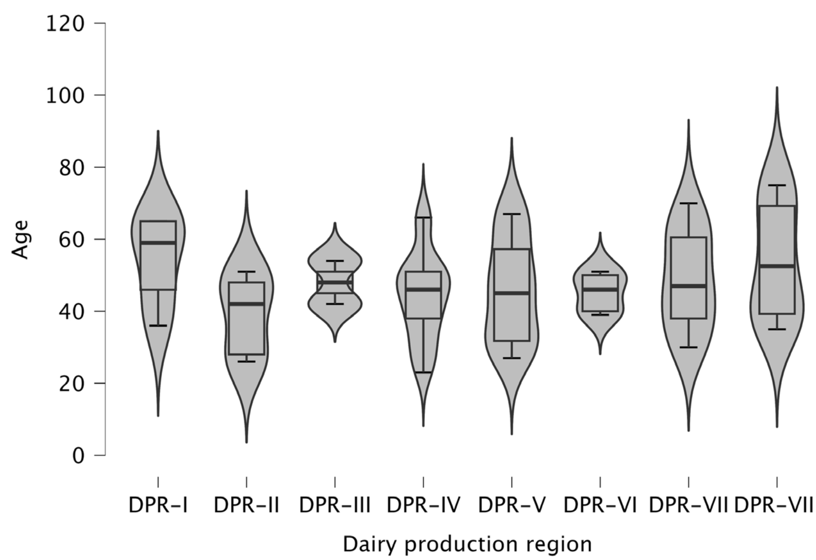

Figure 1b.

Figure 1.
Average age of dairy farmers by (1a) dairy production system and (1b) Chilean dairy production region.

Table 2.
Milk yield per cow and lactation (standard error of the mean) according to farm size as declared by dairy farmers.

Farm size (heads)	Number of Farmer	Milk yield (L/lactation)	SEM
< 50	6	7,667	928
51 to 150	9	6,592	575
151 to 300	15	8,482	942
301 to 500	14	7,476	849
> 500	41	6,693	352

The predominant breed was Holstein-Friesian (52.38%). However, hybrids were also widely used by producers (21.43%). Other breeds used include Jersey (5%), Montbeliarde (2%), and Chilean red Friesian (10%). A proportion of dairy farmers declared other breeds such as Irish, Swedish Red, Red Holstein, Normand, and Irish Friesian, which altogether reached another 10%.

Farmers´ knowledge of heat stress

Most dairy farmers (85%) stated that they had some degree of knowledge or at least an idea about what heat stress was, but only 46% knew how it affected animals (Table 3). Meanwhile, 15% reported having a general idea or never having heard about it. Nevertheless, only 4% declared that they knew how heat stress affects animal health, well-being, and performance. Meanwhile, 71% declared that they knew some thermal comfort index, although only a few dairy farmers spontaneously mentioned the temperature-humidity index (THI), a gold standard worldwide. However, 69%

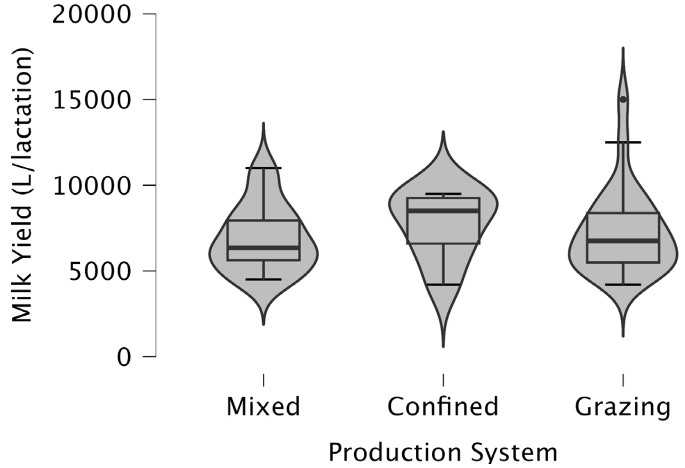

Figure 2a.

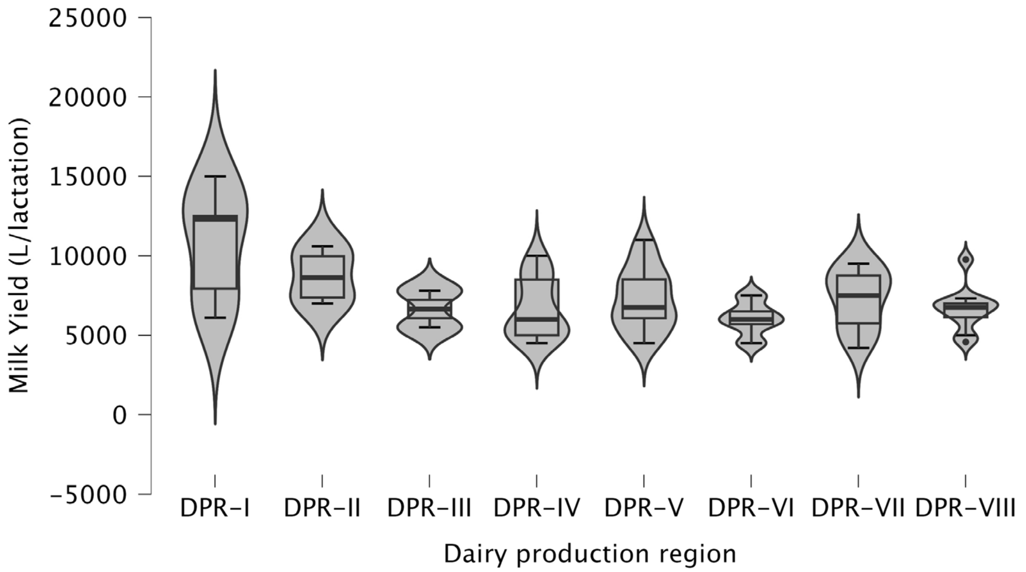

Figure 2b.

Figure 2.
Average milk yield of the herd by (2a) dairy production system and (2b) Chilean dairy production region.

Table 3.
Heat stress knowledge level of Chilean farmers grouped by production systems

Question	Production System	Yes	No
Do you know if there are any ways to minimize the impact of heat stress on dairy cattle?	Confined	71.40%	28.60%
	Mixed	81.80%	18.20%
	Grazing	90.90%	9.10%
Do you consider the issue of heat stress to be relevant to your production system?	Confined	71.40%	28.60%
	Mixed	93.90%	6.10%
	Grazing	92.70%	4.80%
Would you like to receive training on heat stress?	Confined	71.4 %	28.6 %
	Mixed	90.9 %	9.1 %
	Grazing	95.3 %	4.70%
Would you like to have an application for phones or tablets that alerts you to the risk of heat stress and provides suggestions for making decisions about it?	Confined	71.40%	28.60%
	Mixed	84.40%	15.60%
	Grazing	88.0 %	12.00%

indicated that they were able to recognize signs of heat stress in cows, mainly mentioning panting, a drop in production, and the fact that animals looked for shade (Table 4). When asked about mitigation strategies, dairy farmers spontaneously mentioned shade use, water consumption, and sprinkler use.

On the other hand, when asked to mention the most important weather variables affecting animal thermal balance, dairy farmers considered ambient temperature and solar radiation to be the most relevant. Both received nearly the same ratings. However, they were also able to recognize that precipitation, relative humidity, and wind speed were important variables, in that same order. Nevertheless, they were assigned very similar scores to all of them. When they were requested to classify each climatic variable as: "very little relevant", "little relevant", "neutral", "relevant" and "very relevant", 91% considered ambient temperature as relevant or very relevant, while solar radiation reached 83%. In the same sense, it was interesting that 11% of the participants considered solar radiation neutral. In contrast, no one considered ambient temperature to be neutral. Similarly, farmers considered the relative humidity as relevant (41%) or very relevant (33%), while 13% considered it neutral. A similar classification was noted for the rainfall. Finally, the wind speed reached the lowest relevance (68% for relevant + very relevant) but, at the same time, the highest neutrality value (22%).

Importance of heat stress in the production system

Regarding the consideration of dairy farmers about climate change and its consequences on production and animal welfare, 72.6% think that it affects both dimensions. An 8% believe that it affects animal welfare but not its performance, whereas another 10% believe that it does affect them but that animals can cope with it. Finally, 10% thought that it may affect animals a little or not at all and that it is not an issue to be worried about. Most dairy farmers (75%) pointed out that on hot spring-summer days, the milk yield per cow decreased moderately to strongly. However, 19% indicated that milk yield was unaffected by this cause.

Regarding milk quality, only 26% declared that it was negatively affected by heat stress, while 73% believed that there was no effect or that it was neutral. Likewise, 77% indicated that during these days, cows decreased their dry matter intake or grazed for less time during the hottest hours. In addition, most of them indicate that animals consume more water (95%) and spend more time under shade (95%) when available, whether natural or artificial. Meanwhile, 65% declared their perception that reproductive efficiency, that is, the percentage of cows that became pregnant during their estrous cycle, was lower in the summer period. This is a key factor for the profitability of dairy farms.

Heat stress is widely recognized as a significant issue in different dairy production systems. A total of 93.9% of farmers from mixed dairy production systems (MPS), 92.7% from pasture-based systems (PPS), and 71.4% from confined production systems (CPS) considered heat stress to significantly impact their production. Regarding knowledge of strategies to mitigate heat stress, 90.9% of farmers from

Table 4.
Associations between open-ended questions related to knowledge about heat stress and the characterization of participants based on their production systems

Open-ended question*	Answer**	Grazing		Mixed		Confined	
		N°	%	N°	%	N°	%
Are you familiar with any thermal comfort indices applied to dairy cattle?	Temperature humidity index (THI)	2	5%	0	0%	1	14%
	I am not familiar with any	41	95%	28	100%	6	86%
Do you know if there are any methods to minimize the impact of heat stress on dairy cattle?	Weather condition forecasting or comfort thermal indices	1	2%	0	0%	0	0%
	Shade at the waiting yard before milking	20	47%	6	21%	3	43%
	Air fans for cows	11	26%	10	36%	3	43%
	Use of sprinklers	7	16%	10	36%	3	43%
	Available and high-quality water	9	21%	8	29%	1	14%
	Adjustment of milking schedules	3	7%	1	4%	0	0%
	Feed supplements	0	0%	1	4%	5	71%
	Shade at the paddocks	19	44%	8	29%	0	0%
	I am not aware of any measures	4	9%	6	21%	2	29%
Do you know how to recognize if an animal is experiencing heat stress?	Respiratory rate	8	19%	10	36%	1	14%
	Increase in water intake	3	7%	1	4%	0	0%
	Seeking shade	4	9%	4	14%	1	14%
	Decrease in milk production	6	14%	5	18%	1	14%
	Panting	3	7%	5	18%	15	214%
	Reduced estrus	1	2%	0	0%	1	14%
	Increased aggressive temperament	1	2%	0	0%	0	0%
	Reduced activity	2	5%	2	7%	1	14%
	Grouping with other animals	0	0%	1	4%	1	14%
	Activity (sensor)	1	2%	1	4%	0	0%
	I do not know how to identify it	28	65%	9	32%	2	29%

* Open-ended questions in which each respondent could provide more than one answer.
** Each respondent could provide more than one answer.
The percentage is relative to the total number of respondents per dairy production system, pasture-based production system (n = 43), mixed production system (n = 28), and confinement intensive system (n = 7).

PPS, 81.8% in MPS, and 71.4% in CPS reported being aware of management practices to reduce its impact. However, our findings suggest variations in knowledge levels across systems, which appear to be influenced by factors such as direct exposure to climatic conditions in the PPS or higher temperatures in regions where CPS is predominant.

Most farmers (> 85%), regardless of the management system, were unaware of thermal comfort indices such as the temperature–humidity index (THI), the most popular one. Only 5% of respondents from PPS and 14% from CPS mentioned THI, while 95% or more indicated that they were unfamiliar with any thermal index or the effects of heat stress on animals. This finding highlights a critical gap in technical knowledge regarding essential tools for managing heat stress in dairy cattle. Familiarity with these indices could enhance the producers' ability to anticipate heat stress conditions and implement effective preventive measures. Among the reported strategies, the most common were the installation of shade in holding pens (47% in PPS, 21% in MPS, and 43% in CPS) and the use of fans or sprinklers, primarily in mixed and confined systems. Notably, fewer than 50% of farmers mentioned key measures, such as access to quality water or adjustments to milking schedules, despite these strategies being well-documented as essential for mitigating heat stress (Rhoads *et al*., 2009).

The recognition of heat stress signs, such as increased respiratory rate (19% in PPS and 36% in MPS) or reduced milk production (14% in both systems), was not as frequent. However, the latter was more frequent in MPS and CPS. Nevertheless, a high percentage of participants from the PPS (65%) reported being unable to identify signs of heat stress. This could be attributed to the perception that animals with extensive systems are less exposed to heat stress, a notion refuted by studies showing that these systems also face significant risks, especially in warm regions (Collier *et al*., 2006). On the other hand, panting was reported primarily in CPS (21.4%), possibly because of closer observation of animals in these environments. Nevertheless, this represents less than a quarter of the producers. Lastly, subtle signs, such as reduced activity or behavioral changes (e.g., seeking shade or grouping), were underestimated across all production systems despite being critical early indicators of heat stress (West, 2003).

The use of dietary supplements stood out exclusively in confined systems (71%), which may reflect the greater integration of advanced nutritional strategies into CPS. This practice has proven effective in maintaining energy balance and minimizing productive losses during heat periods (Baumgard & Rhoads, 2013). Nonetheless, a significant proportion of producers, particularly those in mixed and extensive systems (21% and 9%, respectively), remain unaware of preventive measures, underscoring the need for targeted technical training in these areas.

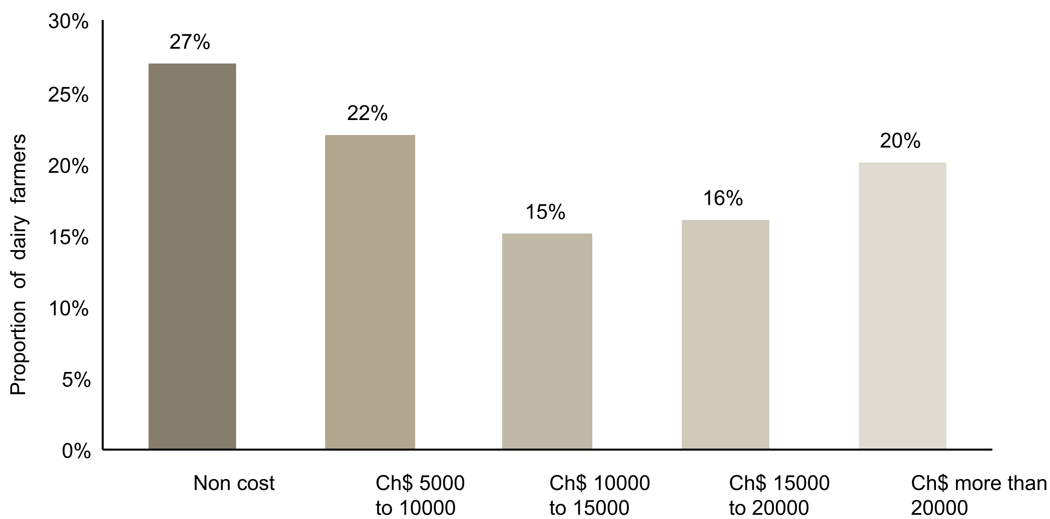

Figure 3.
The proportion of Chilean dairy farmers (n = 85) willing to pay to get access to an early warning system to predict heat stress in Chile.

Training demand and tools to manage heat stress

Most dairy farmers (92.8%) indicated that heat stress was a relevant topic in their production systems and 86% indicated that they knew some mitigation measures. In this sense, the responses varied, predominating the use of shade, fans, increased water availability, and the use of shade in the waiting yard before milking. Only 7.2% of dairy farmers did not consider heat stress relevant to their production systems.

Dairy farmers wanted to be trained in heat stress (91.6%), being the topics of greatest interest by order of preferences: 1) nutritional management under heat stress conditions, 2) reproductive management under heat stress conditions, 3) thermal comfort indices as a management tool, 4) recognition of conditions that favor heat stress, and 5) use of shades to mitigate heat stress. In line with the aforementioned, dairy farmers highlighted a high interest (88%) in having a practical tool, such as an app for cell phones, which allows them to monitor the risk of heat stress and provides suggestions to mitigate its impact. In addition, dairy farmers showed a high interest (88%) in having a practical tool, such as an app for cell phones, that allows them to monitor the risk of heat stress and provide suggestions to mitigate its impact. When asked in more detail about the type of information one app should contain, producers equally prioritized forecasting the risk of heat stress four to seven days in advance and provided recommendations to mitigate the effect of heat stress (24% each).

They also considered it relevant to provide ways to recognize signs when an animal is suffering from heat stress (21%). Meanwhile, 16% raised the possibility of consulting a specialist online, and 14% accessed informative videos. Finally, they were willing to pay an annual subscription to ensure their maintenance and technical support (Figure 3). It should be noted that up to 73% of respondents were willing to do so. Meanwhile, only 27% preferred a free basic version of the app that can only predict the risk of heat stress.

DISCUSSION

Our research aimed to assess the impact of heat stress on Chilean dairy farms in various regions and sizes. We also explored farmers' knowledge of heat stress and their willingness to adopt mitigation strategies, including smartphone apps. According to Lopez (2022), in 2017, there were 4,852 dairy farms in Chile, from the Valparaíso region to the south. However, data from the 2021 Agricultural Census reported 3,750 dairy farms, representing a decrease of 22.7%. However, the number of dairy farms differs according to the number of dairy producers. It is estimated that the number of producers that supply the Chilean dairy industry was 2,048, which is 7% lower than that in 2020 (Anrique, 2022). Of the total number of producers, 93.7% (n = 1,919) were in the southern regions (La Araucanía, Los Ríos, Los Lagos) and 6.3% (n = 129) were in the central zone (Metropolitan region up to Biobío region). The survey was sent to 630 dairy farmers registered in databases of the Chilean Dairy Consortium, APROVAL A.G., FEDELECHE, and De Laval SA, representing 30.8% of the total producers reported by the Chilean Dairy Consortium.

Heat stress evolution in Chile

The detrimental consequences of heat stress in dairy cattle include negative effects on reproduction (Rensis & Scaramuzzi, 2003), milk production (Ouellet *et al*., 2019), rumination (Moretti *et al*., 2017), and cow behavior (Herbut *et al*., 2021; Tsai *et al*., 2020). Over the last few decades, Chile has experienced increasing heat wave trends, especially in the central regions of the country (DPR I, II, and III) (Piticar, 2018). For the period 1981-2010, most cities in Chile recorded between one and two heatwaves each summer. However, since then, heat waves have at least doubled, experiencing between four and five waves per summer. The most extreme case was recorded in 2017 in Curicó City (DPR I), with a heat wave lasting 16 consecutive days (Vicencio, 2018). Similarly, Feron *et al*. (2019) reported that extremely hot days in South America at least doubled during the December-January-February period. Under these conditions, cattle usually suffer from heat stress, which is recognized as a serious problem worldwide, especially in dairy farms with breeds with high milk-producing potential (Carabaño *et al*., 2016).

In the central regions of Chile (DPR I and II), confinement dairy production systems predominate, where the animals have roofs that allow them to be protected from adverse climatic conditions, especially solar radiation during heat waves. Many producers have implemented fan systems, which, despite being quite expensive, are an effective method for reducing air temperature. In contrast, most dairy production systems in southern Chile (DPRs III to VIII) operate under free grazing, where it is necessary to ensure the availability of shade from trees in the paddocks so that the animals can protect themselves from direct solar radiation. The farmers in our survey recognized this as one of the primary measures to mitigate heat stress. Additionally, many respondents highlighted another method to mitigate heat stress, the use of sprinklers in the milking parlor waiting yard, which has been an effective method to promote heat loss through evaporation.

On the other hand, animal welfare has become a determining factor in achieving the best productive potential in dairy cattle, so heat stress is a situation that dairy farmers are concerned about (Foroushani & Amon, 2022; Gutiérrez-Gómez *et al*., 2021; Wankar *et al*., 2021).

Relevance of heat stress: impact on animal production and welfare

Currently, there is limited information regarding the effects of heat stress on dairy cattle in Chile (Arias *et al*., 2008). Indeed, the first studies date back to 2010 (Arias & Mader, 2010), when the potential risk of heat stress in Chile was reported at four locations. It is well known that the productive performance of dairy cattle is directly affected by climatic factors within their productive environment, particularly by environmental temperature, relative humidity, solar radiation, and wind speed, which together affect their thermal balance (Arias *et al*., 2008). Growth, milk production, and reproduction in cattle are affected by heat stress, resulting in drastic changes in their biological functions (Hillman *et al*., 2001). Meneses *et al*. (2021) and Collier *et al*. (1982) stated that when animals suffer from the influence of heat stress, they endure constant depressing situations that can result in a greater frequency of diseases and a decrease in production levels.

One of the main effects of heat stress is a decrease in feed intake, which in turn affects milk composition and yield (Beede, 1993). Dairy yields of Holstein cows decrease between 50 and 75% in environments with temperatures above 26.5°C, the same effect in Jersey and Brown Swiss cows but with temperatures above 29.5°C (Correa-Calderon *et al*., 2004; Liu *et al*., 2019). Regarding reproduction, it affects the absence of heat, decreased heat detection rates, repetition of heat, and embryonic losses, among other consequences (Nanas *et al*., 2021).

Economic losses due to heat stress in dairy cattle have been widely studied worldwide, reaching important figures (Cartwright *et al*., 2023; Key *et al*., 2014; Martinsohn & Hansen 2012; St-Pierre *et al*., 2003). Only in the United States, the dairy industry experiences an annual loss of $5 to $6 billion because of heat stress. Therefore, proper management of heat stress should be undertaken to reduce heat stress, which will help both the economic conditions of farmers and the welfare of dairy cows.

Early warning monitoring for heat stress

The use of early warning mechanisms to predict heat stress in cattle is of great interest. At the global level, the gold standard is the Temperature and Humidity Index (THI), which allows the thermal environment of animals to be characterized and related to the biological response of livestock. At a global level, there are some experiences that, seven days in advance, allow producers to take necessary measures to minimize the effects of heat stress. For example, the United States and Australia, which present a high risk of heat waves, use THI. Australia is projected to experience an additional 31 to 42 days of heat stress annually by 2050 (Nidumolu *et al*., 2014). On the other hand, work carried out in Uruguay by INIA has shown important losses due to physiological and metabolic changes in animals due to the lack of mitigation mechanisms such as THI. Therefore, they developed an early warning system that uses the Global Forecast System

(GFS) model of the US National Oceanic and Atmospheric Administration (NOAA) agency to provide meteorological and potential heat stress information.

CONCLUSIONS

Heat stress is one of the biggest problems faced by dairy farmers globally because of the increasing frequency and occurrence of heat waves in recent years, resulting from climate change, which directly affects milk production and animal welfare. In Chile, there is limited information about this matter, but up to now, no information has been available on the perception of dairy farmers regarding heat stress; this is the first work at the national level. Our results provide the first evidence that Chilean dairy farmers consider heat stress a subject of concern, especially those from grazing and mixed production systems. In addition, they are willing to be trained and have decision-making tools to monitor and mitigate the impact of heat stress. Chilean dairy production systems will face increasing challenges as the number of hot days increases, which generates expectations in the industry to identify solutions that mitigate the negative effects of heat stress on animals.

Data and model availability statement

The data that support the study findings are available upon request and after authorization by the authors.

Author contributions

Conceptualization, R.A., and J.P.K..; methodology, R.A., E.B., and J.P.K.; software, R.A.; formal analysis, R.A., J.H., and R.P.; investigation, R.A. and R.P.; data curation, R.A.; writing—original draft preparation, J.H. and R.A.; writing—review and editing, R.A., J.H., J.P.K. E.B., and R.P.; project administration, R.A.; funding acquisition, R.A. All authors have read and agreed to the published version of the manuscript.

Declaration of interest

The authors declare they have no financial interest.

Acknowledgments

The authors would like to acknowledge the Chilean government for providing funds, to Alejandra Viedma from the Chilean Dairy Consortium and Andrea Gruzmacher from the Association of Milk Producers of the Los Ríos Region for their support in collecting data.

Financial support statement

This research was funded by the project PYT-2022-0159 granted by Foundation for Agricultural Research (FIA) from the Chilean government.

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