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Can meteorological variables affect milk production in different lactation orders of dairy cows in the Cfb climatic zone? A case study in Southern Brazil

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Additional keywords

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SUMMARY

Data from 5689 lactating cows in 35 different dairy herds in Southern Brazil were evaluated over a 15-year period to examine the influence of meteorological variables on milk production in dairy cows with primiparous (1st) and multiparous (2nd to 4th) lactation. Meteorological variables considered were maximum and minimum temperature, relative humidity of air, solar radiation, wind speed, precipitation and temperature and humidity index corrected for solar radiation and wind speed (THIc). Data were submitted to principal component analysis (PRINCOMP), Pearson correlation (CORR) and step-by-step (STEPDISC) discriminant analyses, using the Statistical Analysis System (SAS®). Primiparous and multiparous cows were negatively affected by maximum temperature in summer, while the higher the minimum temperature in winter was, the better the milk production was. Primiparous cows produced, on average, 28.17 kg/day of milk and were 26.15 months old while the multiparous cows in average produced 30.76 kg/day and were 54.47 months old. The greatest average maximum temperature recorded during the 15 years of observations did not exceed 30°C and the THI corrected were maintained within acceptable values for animal thermal comfort. Lactation order and milk production showed a negative and significant correlation with minimum temperature, but with low magnitude. Milk production of multiparous cows was negatively affected by maximum temperature in summer and milk production of both categories were affected negatively by minimum temperature in fall. The principal component analysis did not show any association between milk production, lactation order and meteorological variables. Discriminant analysis presented significant values for meteorological variables, but with very low values of partial R^2 estimated. Meteorological variables in a Cfb climatic zone did not negatively affect milk production in primiparous and multiparous lactating cows.

As variáveis meteorológicas podem afetar a produção de leite de vacas leiteiras com diferentes ordens de lactação na zona climática Cfb? Um estudo de caso no Sul do Brasil

Palavras-chave adicionais

Classificação de Köppen.
Clima temperado.
Condições climáticas.
Vacas em lactação.

RESUMO

Os dados de 5689 vacas em lactação de 35 rebanhos leiteiros diferentes no Sul do Brasil foram avaliados durante um período de 15 anos para examinar a influência de variáveis meteorológicas na produção de leite em vacas leiteiras primíparas (1° lactação) e multíparas (2° a 4° lactações). As variáveis meteorológicas consideradas foram a temperatura máxima e a mínima, a umidade relativa do ar, a radiação solar, a velocidade do vento, a precipitação e o índice de temperatura e umidade corrigido para a radiação solar e a velocidade do vento (ITHc). Os dados foram submetidos à análise de componentes principais (PRINCOMP), correlação de Pearson (CORR) e análise discriminante step-by-step (STEPDISC), utilizando o programa estatístico SAS (SAS®). As vacas primíparas e multíparas foram afetadas negativamente pela temperatura máxima no verão, entretanto, quanto maior a temperatura mínima no inverno melhor a produção de leite. Vacas primíparas produziram, em média, 28,17 kg de leite por dia e apresentaram idade média de 26,15 meses, enquanto que as vacas multíparas produziram em média 30,76 kg de leite por dia e apresentaram idade média de 54,47 meses. A maior temperatura média máxima registada durante os 15 anos de observações não excedeu os 30°C e o ITH corrigido foram mantidos dentro de valores aceitáveis para o conforto térmico animal. Ambas as ordens de lactação e a produção de leite apresentaram correlação negativa e significativa com a temperatura mínima, mas com baixa magnitude. A produção leiteira de vacas multíparas foi afetada negativamente pela temperatura máxima no verão e a produção leiteira de ambas categorias foram afetadas negativamente pela temperatura mínima no outono. A análise de componentes principais não apresentou nenhuma associação entre a produção de leite, a ordem de lactação e as variáveis meteorológicas. As análises discriminantes apresentaram valores significativos para as variáveis meteorológicas, mas com valores muito baixos do coeficiente de correlação (R^2) parcial estimado. As variáveis meteorológicas em uma zona climática Cfb não afetaram negativamente a produção de leite em vacas primíparas e multíparas.

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INTRODUCTION

Good management of dairy cattle involves adequate nutrition, herds with high genetic merit and environmental conditions than allow for high milk production without compromising animal welfare (Von Keyserlingk *et al*., 2012; Ingvartsen and Moyes, 2013; Barkema *et al*., 2015). High producing dairy breeds such as British and Continental European breeds have been reared in subtropical and temperate regions, with mild climate, or when temperature and relative humidity values do not cause thermal stress in the animals (Edwards *et al*., 2011; Orlando, 2015; Schafberg and Swalve, 2015).

Commercial milk herds use animals up to their maximum level of production. Often this means keeping females in the herd producing up to 4th or 5th lactations (Ray *et al*., 1992). Pak production in the Holstein breed can occur from the 3rd lactation on (Pollott, 2011). On other hand, higher production results in a higher metabolic activity, increasing heat production and the need for a more favorable thermal environment for these animals at higher production levels (Karimi *et al*., 2015; Qi *et al*., 2015). Multiparous lactating cows also have higher metabolic activity due to simultaneous pregnancy with on-going lactation period (Wathes *et al*., 2007).

Much of the Brazilian territory is located in tropical regions (CIA, 2013) where year-long high temperatures are a barrier to the best expression of milk potential of high performance dairy cows. However, in southern Brazil, some regions are classified as Cfb climate classification zone (Cruz, 2007; Alvares *et al*., 2013) with mild summers (mean temperature below 22º C in hot season) and occasionally rigorous winters (more than 5 night frosts per year). These characteristics are ideal for milk production from dairy breeds of European origin, such as the Holstein and Jersey, principally in animals with high levels of milk production (Hill and Wall, 2015).

The objective of this study was evaluated the influence of meteorological variables on milk production of dairy cows with different lactation order in a Cfb climate classification zone in Southern Brazil.

MATERIAL AND METHODS

The database utilized for milk yield production was obtained from Milk Recording Services of the Brazilian Association of Holstein Breeders collected in Castro region, in the Center-west of Parana State in the Southern Region of Brazil (24°47′27″ S and 50°0′43″ W) with average altitude of 988 meters. The climate was Cfb (humid temperate), according to Köppen classification system, characterized by mild temperatures in spring and summer and occasionally rigorous winters (Peel *et al*., 2007).

This region has the most developed dairy system of Parana State, based on farms with area ranging between 60 to 80 ha. Milk production was intensive, with use of confinement or free-stall, using alfalfa hay and grass, annual and perennial forages, as well as the use of concentrate throughout the year. Artificial insemination was used in 100% of the females, and calvings were distributed over the whole year. Milking was 100% mechanized, in some cases robotized, and milk cooling was realized on-farm.

Over a 15 year survey period, 161,351 test day milk yield records from 1,563 primiparous (1st lactation) and 4,126 multiparous cows (2nd to 4th lactation) from 35 different herds were computed, considering animal and herd identification, test day milk yield, calving date, lactation order, length of lactation and cow age. Characteristics of both groups used in the survey are described in **table I**.

Meteorological data from the same period were obtained from the National Institute of Meteorology (INMET) from Meteorological Station Nº WMO 83813 in Castro municipality (24°48′S, and 50°0′W with altitude of 1,008.80 meters). The farms used in the survey were located in a maximum perimeter of 40 km in a straight line from the meteorological station. Data collected included air temperature (mean, minimum and maximum), relative humidity of air, wind speed and solar radiation, gathered daily at 0:00 and 12:00 Greenwich Mean Time (GMT). The total data set was composed of 10,162 meteorological data described in **figure 1**.

From the meteorological data, the Temperature and Humidity Index (THI) and Temperature and Humidity Index corrected for solar radiation and wind speed (THIc) were calculated according to MADER *et al*. (2004): THI= {(0.8 * environmental temperature) + (% relative humidity/100) * (environment temperature – 14.3)) + 46.4} and THIc = {(6.81 + THI) – (3.075 * wind speed) + (0.00055 * solar radiation)}.

Data were standardized (PROC STANDARD), with mean equal zero and standard deviation equal 1 and milk production clustered into primiparous (1st lactation) and multiparous cows (2nd to 4th lactation). Variance inflation factors (PROC REG option VIF) were verified, where variables with VIF value greater than

Table I. Characteristics of primiparous and multiparous cows used in the survey (Características das vacas primíparas e multíparas utilizadas na pesquisa).

	Primiparous cows	Multiparous cows
Number of cows	1563	4126
Milk production (kg/day)	28.17± 6.74	30.76± 9.01
Age (months)	26.15±4.27	54.47±14.72
Number of lactation	1	2.88±0.75
Lenght of lactation	161.14±96.29	170.04±100.15

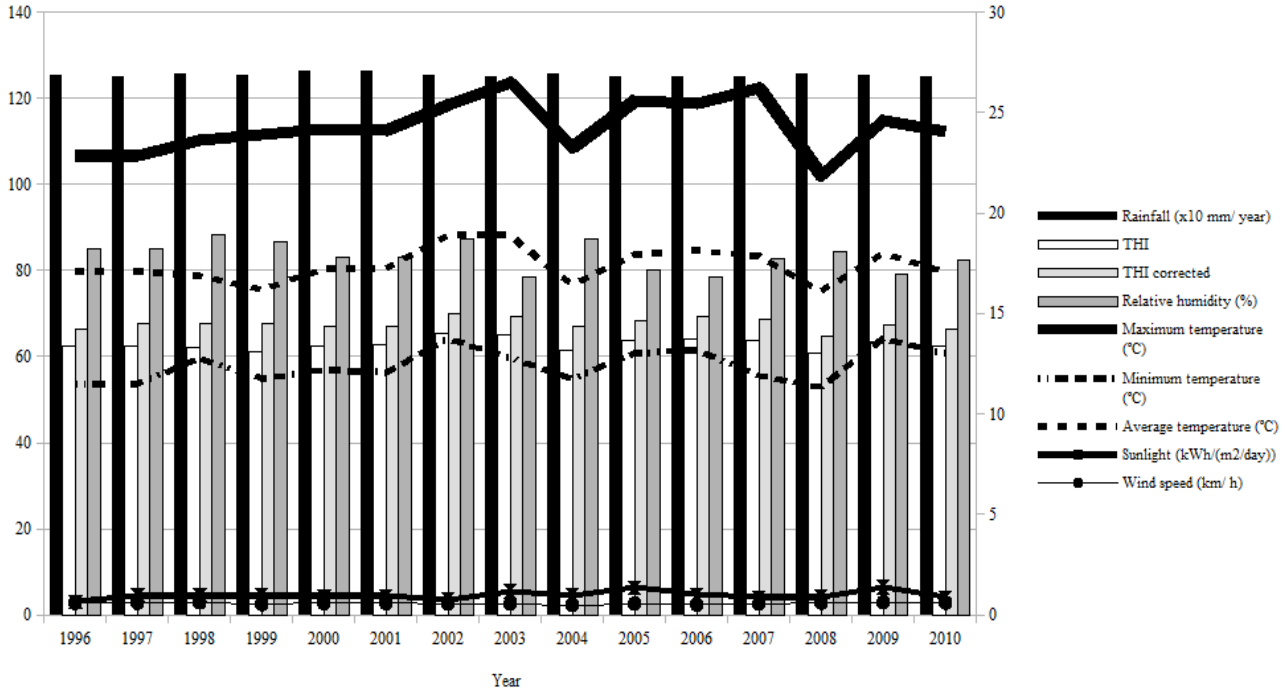

Figure 1. Meteorological variables observed in Weather Station in Castro, Paraná, Brazil, over a 15 year survey period (Variáveis meteorológicas observadas na estação meteorológica em Castro, Paraná, Brasil, durante o período de 15 anos da pesquisa).

10 were removed from the analysis. THI, in this case was removed and only utilized to calculate THIc values. A general (15 year survey period) and per season (summer, autumn, winter and spring) analysis of data was carried out. For this, data were submitted to a multivariate statistical analysis including principal factor analysis (PROC FACTOR), to observe relationship between the variables and a step-by-step discriminant analysis (PROC STEPDISC) to identify the importance of each climatic variable in relation to milk production.

Pearson's correlations (PROC CORR) between milk production and meteorological variables for a general and per season were also calculated. All statistical analysis were carried out using SAS ® for Windows version 9.3 (Statistical Analysis Institute, Cary, North Carolina).

RESULTS

Correlations analysis over 15 year survey period showed that primiparous cows were more sensible to meteorological variables that multiparous cows, even though correlations for all variables were low **(Table II)**. Minimum temperature affected milk production of both categories negatively, while maximum temperature affected multiparous cows negatively. THIc did not show any significant correlation with milk production for both primiparous and multiparous cows.

Multiparous cows suffered a negative influence of the maximum temperature in the summer, reflecting a negative correlation between THIc and milk production in animals of this category **(Table II)**. Therefore, in the winter, these animals suffered a positive influence of the maximum temperature on milk production, indicating that the maximum temperature could be used as meteorological indicator to evaluate the association between climatic welfare and milk production.

The principal factor analysis for milk production of primiparous and multiparous cows and meteorological variables during 15 year period showed that the first two principal factors explained 95% of total variance **(Figure 2)**. Cow age and lactation order showed high communality due own high variance, but there was not any interaction or association among milk production and meteorological variables. The higher the milk production the higher the age and the lactation number of the cows.

The principal factor analysis for seasons **(Figure 3)** showed that when meteorological variables reach extreme values, as occurs in summer and winter, they could affect milk production of the cows in different lactation orders. In summer, minimum temperature and rainfall were associated with milk production, while relative humidity and solar radiation and, consequently, THIc, negatively affected milk production. In winter, maximum temperature and relative humidity had negative relation with milk production, but solar radiation was associated positively with milk production, which compensated with a smaller influence of the THIc over milk production.

Step-by-step discriminant analyses are presented in the **table II**. For general or seasonal analysis, meteorological variables presented significance in multi-

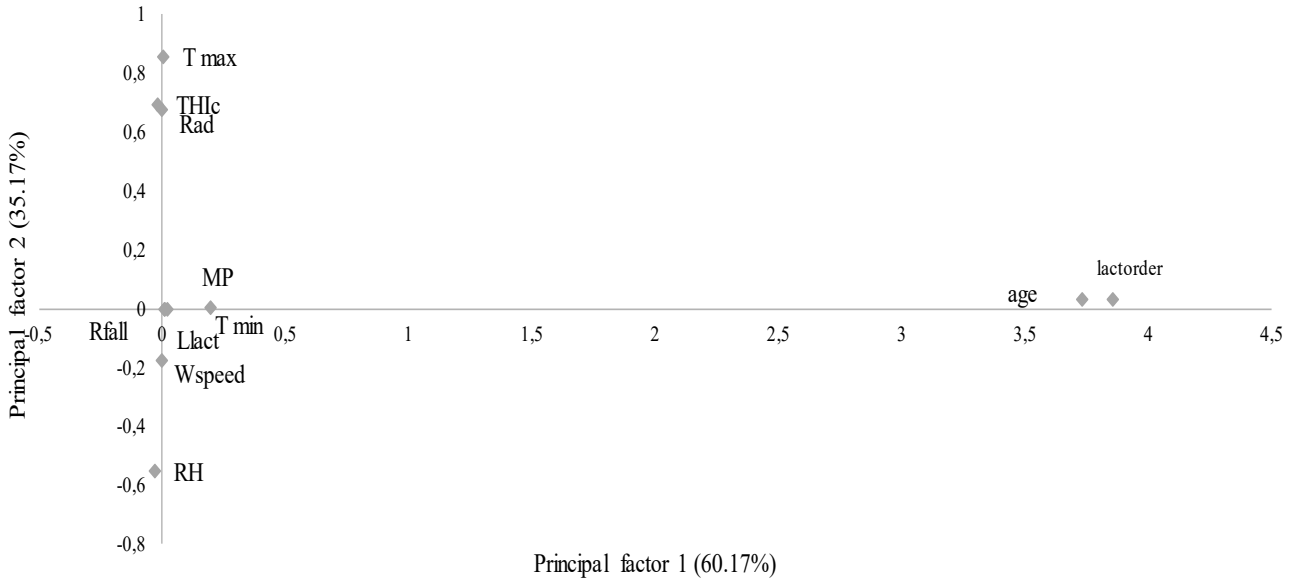

Figure 2. Principal factor analysis for milk production of primiparous and multiparous cows and meteorological variables over a 15-year survey period. MP: daily milk production; Age: cows age; Llact: length of lactation; lactorder: lactation order; T min: minimum temperature; T max: maximum temperature; Rfall: rainfall; WSpeed: wind speed; RH: relative humidity; Rad: solar radiation; THIc: temperature and humidity index corrected for solar radiation and wind speed (Análise de fatores principais para a produção de leite de vacas primíparas e multíparas e variáveis meteorológicas durante o período de 15 anos da pesquisa. MP: produção diária de leite; Age: idade das vacas; Llact: duração da lactação; lactorder: ordem de lactação; T min: temperatura mínima; T max: temperatura máxima; Rfall: precipitação; WSpeed: velocidade do vento; RH: umidade relativa; Rad: radiação solar; THIc: índice de temperatura e umidade corrigidos para a radiação solar e a velocidade do vento).

variate and F test, but values for R^2 partial estimated were low, which means that the variables selected were important but were not enough to affect positively or negatively milk production of dairy cows with different lactation orders.

DISCUSSION

In regions with subtropical or temperate climate, milk production is affected by extremes of meteorological variables (Hill and Wall, 2015). However, in this study, meteorological variables did not affect milk production of cows with different lactation orders, in the Castro region of southern Brazil, possibly due to high technological level of dairy production as well as a positive influence of the soil and climatic conditions of the region on the animal welfare (Silva, 2006), corroborating with Hammami *et al*. (2009), Renaudeau *et al*. (2012) and Schüller *et al*. (2014), who stated that adequate climates for dairy cattle breeds were those with mild summers and mean temperatures between 19 and 24ºC.

Therefore, minimum temperature was an important variable when the relation between meteorological variable and milk production from cows with different lactation order in a Cfb climate zone were evaluated. According to Mader *et al*. (2010), younger animals can be affected negatively by temperatures below 10ºC, as observed for primiparous cows compared with multiparous.

In Pearson's correlation analysis for the 15 year period studied here, milk production of multiparous cows was negatively affected by maximum temperature, a common condition of European dairy breeds when air temperature is above 26ºC (Berman, 2011). Events of high temperature or THI in Cfb climate zone are not common, but when they do happen, the high level of milk production from multiparous cows increases metabolic heat and the high temperatures affect negatively milk production in this category of dairy cows (West, 2003; Bernabucci *et al*., 2014).

Factor analysis over a 15 year survey period did not show any association or inverse relation between meteorological variables and milk production, demonstrating that the cows, regardless of the lactation order were adapted to the Cfb climate or this climate has the similar characteristics to where European dairy cattle breeds were developed (Ravagnolo *et al*., 2000; West, 2003; Bernabucci *et al*., 2010). However, the influence of meteorological variable on milk production was observed between seasons, mainly summer and winter, corroborating with Hill and Wall (2015), who observed a great influence of some meteorological variables, such as solar radiation and THI, in Holstein cows established in Scotland in summer and winter seasons.

In summer and winter, solar radiation presented an inverse and direct relationship, respectively, with milk production of primiparous and multiparous cows. This relation was based on the difficulty of cows to dissipate heat in summer, when solar radiation contributes to an increase of air temperature (Williams *et al*., 1960). Therefore, the results observed in this study are divergent those found by Dahl *et al*. (2012) where a long photoperiod, characteristic of summer season, allowed an increment of milk

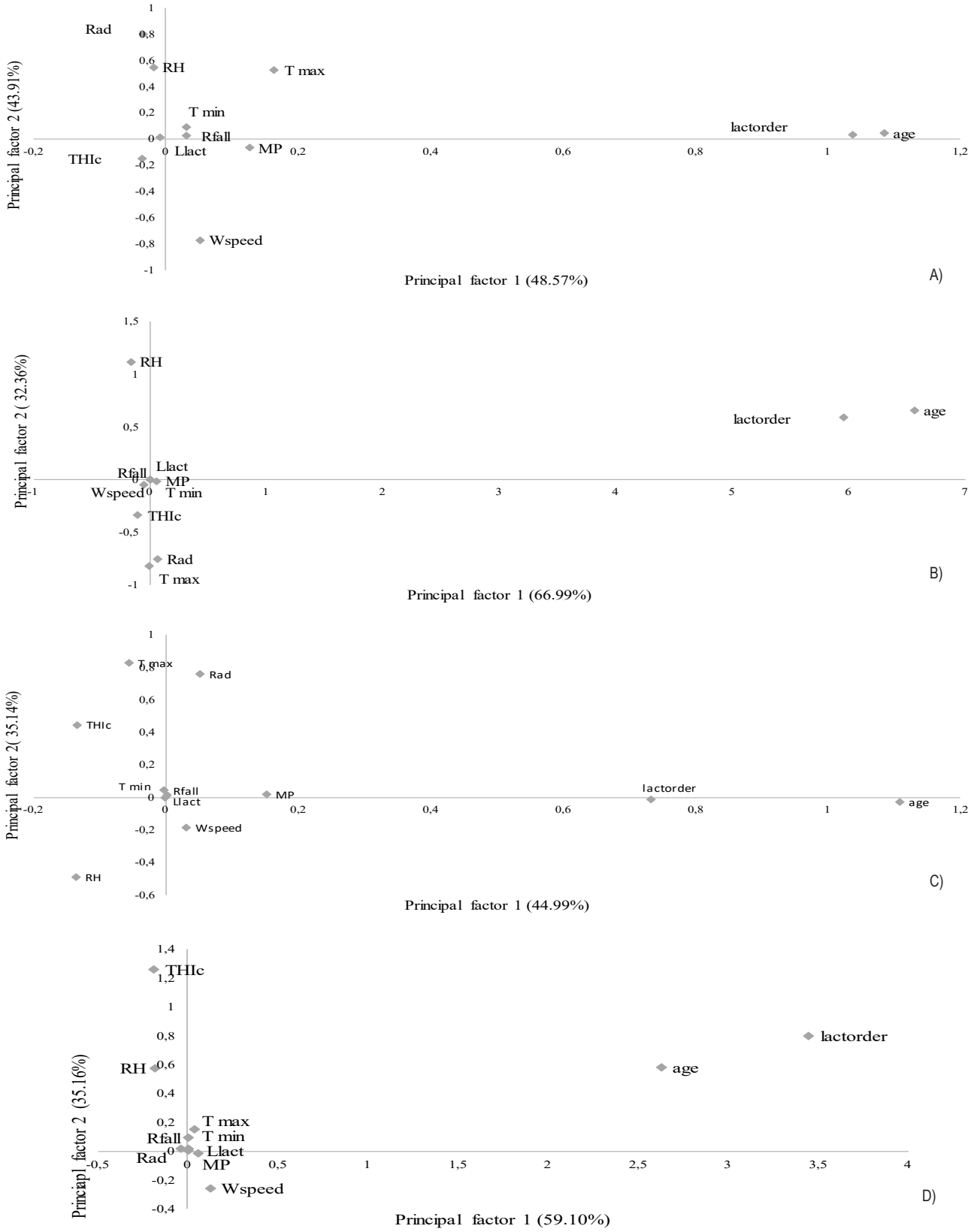

Figure 3. Principal factor analysis for milk production of primiparous and multiparous cows and meteorological variables in summer (A), fall (B), winter (C) and spring (D) over a 15-year survey period. MP: daily milk production; Age: cows age; Llact: length of lactation; lactorder: lactation order; T min: minimum temperature; T max: maximum temperature, Rfall: rainfall; WSpeed: wind speed; RH: relative humidity; Rad: solar radiation; THIc: temperature and humidity index corrected for solar radiation and wind speed (Análise de fatores principais para a produção de leite de vacas primíparas e multíparas e as variáveis meteorológivas no verão (A), outono (B), inverno (C) e primavera (D) durante o período de 15 anos da pesquisa. MP: produção diária de leite; Age: idade das vacas; Llact: duração da lactação; lactorder: ordem de lactação; T min: temperatura mínima; T max: temperatura máxima; Rfall: precipitação; WSpeed: velocidade do vento; RH: umidade relativa; Rad: radiação solar; THIc: índice de temperatura e umidade corrigidos para a radiação solar e a velocidade do vento).

Table II. Pearson's correlation analysis between meteorological variables and milk production of primiparous and multiparous cows over 15-year period and for climatic seasons in Southern Brazil (Análises de correlação de Pearson (r) entre as variáveis meteorológicas e a produção de leite das vacas primíparas e multíparas durante o período de 15 anos e para as estações climáticas no Sul do Brasil).

Lactation order	Rainfall (r) (p>|t|)	Maximum temperature (r) (p>|t|)	Minimum temperature (r) (p>|t|)	Solar radiation (r) (p>|t|)	Relative humidity (r) (p>|t|)	Wind speed (r) (p>|t|)	THI corrected (r) (p>|t|)
				15 year period			
Primiparous cows	-0.021	0.007	-0.049	0.013	-0.02	0.004	-0.003
	<0.0001	0.155	<0.0001	0.004	<0.0001	0.391	0.541
Multiparous cows	-0.005	-0.007	-0.034	-0.001	-0.006	0.005	-0.005
	0.073	0.015	<0.0001	0.872	0.047	0.096	0.114
				Summer			
Primiparous cows	-0.007	-0.007	0.003	0.023	0.024	0.003	-0.014
	0.142	0.422	0.707	0.01	0.008	0.752	0.117
Multiparous cows	0.028	-0.042	-0.009	-0.001	-0.003	-0.002	-0.031
	<0.0001	<0.0001	0.108	0.992	0.563	0.795	<0.0001
				Fall			
Primiparous cows	0.003	0.013	-0.05	0.001	-0.021	0.013	0.007
	0.562	0.145	<0.0001	0.879	0.02	0.145	0.46
Multiparous cows	-0.007	0.008	-0.048	-0.009	-0.007	0.011	0.008
	0.161	0.196	<0.0001	0.144	0.224	0.051	0.184
Winter				Winter			
Primiparous cows	-0.016	0.03	-0.009	0.0068	-0.013	0.005	0.008
	0.002	0.001	0.338	0.513	0.16	0.558	0.385
Multiparous cows	0.015	0.0235	0.003	-0.001	-0.004	0.012	0.028
	0.003	<0.0001	0.634	0.984	0.486	0.051	<0.0001
				Spring			
Primiparous cows	-0.003	-0.012	-0.028	0.018	-0.016	-0.002	-0.011
	0.53	0.174	0.002	0.05	0.074	0.818	0.244
Multiparous cows	0.011	0.016	-0.005	0.006	-0.002	-0.006	-0.015
	0.031	0.009	0.438	0.299	0.717	0.322	0.014

production, by hormonal and metabolic process, and in winter, a short photoperiod, reduced milk production by same process.

There was an inverse relation between THIc and milk production in the summer and in the winter seasons, but the components of the THI used to estimate heat stress varied between seasons. In summer, relative humidity and solar radiation were the components which influenced THIc. The influence of relative humidity was described by Bohamova *et al*. (2007) as principal weight in situations with mild temperatures and humid climates. In a study carried out in Germany, in Cfb climate zone, Sanker *et al* (2013) observed values for THI upper to 60 in summer months, particularity due to high relative humidity during this period, with consequently decreases the health conditions of lactating cows.

In winter, whereas maximum temperature and relative humidity were major contributors of THIc, solar radiation and wind speed decreased the capacity of THI influence negatively the milk production. Solar radiation provides heat over skin and in cold environments this is a mechanism to increase body temperature of animals (Williams *et al*., 1960). Wind speed had the capacity to carry heat from the skin of the animal, reducing superficial temperature (Mader *et al*., 2010). Hill and Wall (2015) verified that, for primiparous or multiparous Holstein cows in Scotland, wind speed was highly significant on milk production per cow in the winter period due to a strong reduction of THIc due to solar radiation and wind speed. But, in the summer period, wind speed contributed to decrease THI when maximum temperature and relative humidity could negatively influence THI levels.

The low influence of meteorological variables in the discriminant analysis was also observed by Verwoerd *et al*. (2006); Dikmen and Hansen (2009); Aguilar *et al*. (2010); Berman (2011); Renaudeau *et al*. (2012) and Van Vuuren and Chilibroste (2013) where dairy breed developed in temperate and subtropical areas was well adapted in the same conditions around the world, and meteorological variables can show deleterious effects over milk production when the cows are exploited in warm regions.

CONCLUSIONS

Meteorological variables do not affect significantly milk production of primiparous and multiparous cows in Cfb climate zone classification.

Table III. Step-by-step discriminant analysis for the determination of meteorological and performance variables of primiparous and multiparous cows in different seasons from 1996 to 2010 in Southern Brazil (Análise discriminante step-by-step para a determinação das variáveis meteorológicas e de desempenho de vacas primíparas e multíparas durante o período de 15 anos em diferentes estações no Sul do Brasil).

Variables	R^2 partial	p > F	p> ASCC[1]
15 year period			
Lactation order	0.5110	< 0.0001	< 0.0001
Milk production	0.0249	< 0.0001	< 0.0001
Length of lactation	0.0084	< 0.0001	< 0.0001
Rainfall	0.0001	0.0002	< 0.0001
Solar radiation	0.0001	0.0018	< 0.0001
Summer			
Lactation order	0.5025	< 0.0001	< 0.0001
Milk production	0.0279	< 0.0001	< 0.0001
Length of lactation	0.0063	< 0.0001	< 0.0001
THI corrected	0.0024	< 0.0001	< 0.0001
Wind speed	0.0004	< 0.0001	< 0.0001
Solar radiation	0.0002	0.0106	< 0.0001
Minimum temperature	0.0001	0.0426	< 0.0001
Fall			
Lactation order	0.5008	< 0.0001	< 0.0001
Milk production	0.0278	< 0.0001	< 0.0001
Length of lactation	0.0092	< 0.0001	< 0.0001
THI corrected	0.0010	<0.0001	< 0.0001
Rainfall	0.0003	0.0007	< 0.0001
Wind speed	0.0002	0.0072	< 0.0001
Maximum temperature	0.0001	0.0401	< 0.0001
Relative humidity	0.0002	0.0031	< 0.0001
Winter			
Lactation order	0.5136	< 0.0001	< 0.0001
Milk production	0.0225	< 0.0001	< 0.0001
Length of lactation	0.0110	< 0.0001	< 0.0001
THI corrected	0.0023	< 0.0001	< 0.0001
Wind speed	0.0002	0.0038	< 0.0001
Spring			
Lactation order	0.5197	< 0.0001	< 0.0001
Milk production	0.0219	< 0.0001	< 0.0001
	0.0073	< 0.0001	< 0.0001
Solar radiation	0.0006	<0.0001	< 0.0001
Minimum temperature	0.0005	< 0.0001	< 0.0001
Wind speed	0.0003	0.0002	< 0.0001
Relative humidity	0.0002	0.0053	< 0.0001
THI corrected	0.0002	0.0019	< 0.0001

[ASSC]Average square of canonical correlation.

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