Productive and reproductive performance of Holstein cows in Agreste, Pernambuco, from 2007 to 2017

Desempenho produtivo e reprodutivo de vacas Holandesas no Agreste de Pernambuco, no período de 2007 a 2017

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Highlights:
Cows raised in the Agreste region produced an average of 32.46 kg milk per day.
Primiparous cows presented higher levels of milk components.
There was a significant increase in the SCS with the increase in the order of calving.
The Wood model showed a good fit of lactation curve.

Abstract

The aim of this study was to assess the productive and reproductive performance of Holstein cows grown in the Agreste region of Pernambuco. Dairy records were collected from three farms located in the Agreste region of the state of Pernambuco each month between 2007 and 2017. According to the National Institute of Meteorology the average annual temperature during the collection period was 24.21 ºC, mean annual rainfall was 551.7 mm and mean annual relative humidity was 75.92%. A total of 42,677 data points concerning milk production, milk components and somatic cell score (SCS), as well as other zootechnical information regarding reproductive management, are analyzed herein. In order to assess cow productive performance, lactation curve estimates were performed according to calving order by applying the Wood model, while milk production, milk components and SCS were analyzed according to calving order and farm, season, calving year and the interaction between calving order and season. Regarding reproductive evaluations, farm effects on indices such as age at first calving (IPP), calving interval (IP) and service period (PS) were evaluated. Data were processed using analysis of variance SAS PROC GLM commands, while PROC NLIN commands were used to estimate the curves. Significant ($p < 0.05$) farm, calving order, season, calving year and interaction effects on production values, milk composition and SCS were noted. Higher amounts of certain milk components (lactose, total solids and non-fat solids) were observed in primiparous cows. Multiparous cows were the most productive in relation to the amount of milk produced milk (34.15 kg/milk/day) and, consequently,

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presented the highest SCS (4.48). The Wood model showed a good fit of lactation curve characterized by an ascending phase until peaking and a descending phase following the peak. Regarding the assessed reproductive indices, a significant effect (p < 0.05) of farm was observed on IP and PS. The parameters calving order, farm, season, year of calving, interaction between calving order and season, as well as the effect of farm on reproductive indices (IP and PS) are the most important factors in the evaluation of production and milk quality of cows raised in semiarid environments.
Key words: Dairy cattle. Dairy control. Lactation curve. Milk quality. Zootechnical indices.

Resumo

Objetivou-se com este trabalho avaliar o desempenho produtivo e reprodutivo de vacas holandesas criadas no Agreste de Pernambuco. Foram analisados registros de controle leiteiro obtidos em três fazendas localizadas na região Agreste do estado de Pernambuco, realizados mensalmente entre os anos de 2007 e 2017. As características climáticas, de acordo com o Instituto Nacional de Meteorologia, para o período de coleta foram: temperatura média anual de 24,21ºC; precipitação média anual de 551,7 mm e umidade relativa média anual de 75,92%. Um total de 42.677 informações sobre produção de leite, componentes do leite e escore de células somáticas (ECS) e outras informações de controle zootécnico referente ao manejo reprodutivo foram analisados neste estudo. Para avaliar o desempenho produtivo das vacas, foram feitas estimativas das curvas de lactação em função da ordem de parto utilizando o modelo de Wood e a produção de leite, componentes do leite e ECS foram analisados em função da ordem de parto e quanto aos efeitos de fazenda, estação do ano e ano de parto e a interação ordem de parto e estação do ano. Para avaliação reprodutiva, foi avaliado o efeito da fazenda sobre os índices como idade ao primeiro parto (IPP), intervalo de parto (IP) e período de serviço (PS). Os dados foram processados usando os comandos do SAS, PROC GLM para análise de variância e PROC NLIN para estimativa das curvas. Houve efeito significativo (p < 0,05) de fazenda, ordem de parto, estação do ano, ano de parto e da interação analisada, sobre os valores de produção, composição do leite e ECS. Os maiores teores de alguns componentes (lactose, sólidos totais e sólidos não gordurosos) do leite foram observados nas primíparas. As vacas multíparas foram as mais produtivas em relação à quantidade de leite produzido diariamente (34,15 kg/leite/dia) e consequentemente, apresentaram maior ECS (4,48). O modelo de Wood apresentou bom ajuste aos dados, apresentando uma curva caracterizada por uma fase ascendente até o pico e uma fase descendente posterior ao pico. Para os índices reprodutivos, observou-se efeito significativo (p < 0,05) de fazenda sobre o IP e PS. Os parâmetros ordem de parto, fazenda, estação do ano, ano de parto, interação entre ordem de parto e estação do ano, assim como o efeito de fazenda nos índices reprodutivos (IP e PS) são os fatores mais importantes na avaliação da produção e qualidade do leite de vacas de alta produção criadas no semiárido.
Palavras-chave: Bovinocultura leiteira. Controle leiteiro. Curva de lactação. Qualidade de leite. Índices zootécnicos.

Introduction

The increase in livestock production in Brazil has led to the country being one of the main suppliers of animal food worldwide. Although Brazil has one of the largest cattle herds (214.9 million head) and ranks fourth in milk production on the world stage (33.5 billion liters), the productivity of the national herd is low (approximately 1,963 liters/cow/year) (Instituto Brasileiro de Geografia e Estatística [IBGE], 2017), which highlights the need to improve the productive and reproductive efficiencies of dairy herds (Martins, Rocha, Resende, Carvalho, & Freitas, 2018a).

Gains in productivity and milk quality are the main mechanisms for ensuring the efficiency and sustainability of production systems in the scenario of recent agro-industry transformations in Brazil and worldwide. Among the factors that should be considered in attempts to increase the productive and reproductive indices of cattle are care for the

environment, guaranteeing milk safety, animal welfare, breed and the animal purpose (Silva et al., 2011).

Among the various breeds with an aptitude for dairy production is the Holstein breed, which is present in most developed livestock-producing countries. In Brazil, this breed has been the basis of several crossings, ensuring a wide range of genetic variability in herds around the country (Martins, Zoccal, Rentero, & Albuquerque, 2018b).

The Holstein breed originates from temperate climates and may suffer limitations when raised in semiarid regions, which have high temperatures (with annual averages ranging from 23 °C to 27 °C), a low relative humidity (equal to or less than 50%), a low rainfall index (less than 800 mm per year), irregular and scarce rainfall, and nutrient-poor soils. These factors that limit the availability and quality of forage during the year (Teixeira, 2016), and may make it impossible to achieve the maximum productive capacity of cows selected for higher milk production (Cerutti, Bermudes, Viégas, & Martins, 2013). To obtain satisfactory productive and reproductive results, it is necessary to adapt the environmental conditions to the animals using climatic strategies to reduce the effects of thermal stress on lactating cows and improve the thermal comfort indices (Cerutti et al., 2013).

Other factors that can influence milk productivity and quality, in addition to environmental factors, are physiological factors, such as age at first calving, birth order and lactation period (Chegini, Ghavi, Hosseini, & Shadparvar, 2017). The changes that occur with the advancement of age are mainly caused by physiological factors and lead to maximum performance at maturity followed by a decrease as the animal ages, an effect that is directly related to the order of calving (Soares, Rangel, Aguiar, Medeiros, & Lima, 2009).

Understanding the effect of the season, the lactation curve, and age at calving on the productive performance of cows is important for the determination of management techniques and is fundamental in decision-making when selecting animals in breeding programs. Thus, this study was performed to evaluate the productive and reproductive performance of Brazilian Holstein cows raised in a semiarid region of Pernambuco state.

Material and Methods

Characterization of the study site

To carry out this study, data on milk production and composition were collected from three commercial dairy herds of Holstein cows, located in the cities of Gravatá and São Bento do Una, in the Agreste region of Pernambuco state, Brazil. According to the National Institute of Meteorology (INMET) the climatic characteristics for the 11 years of data collection were as follows: average annual temperature 24.21 ºC (minimum 20.43 ºC, maximum 30.03 ºC); average annual rainfall 551.7 mm (minimum 376.9 mm, maximum 859.4 mm) and average annual relative humidity 75.92% (minimum 73.30%, maximum 78.14%) (Table 1).

Characterization of farms

We collected 6,350 official monthly milk monitoring records between January 2007 and December 2017. The herds were producing milk under a semi-arid climate and with similar food management, using a concentrated commercial feed based on corn and soybean, and forage palm, corn silage and Tifton hay. Mineral salt and water were available *ad libitum.*

The records were collected from three farms with representative number of animals. The facilities of the three farms were similar, with sheds with feeders and drinkers and free access to a sand bed, except on farm two, which had a *free stall* shed with fans, sprinklers and rotating brushes.

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Table 1
Average values of climate variables according to the season during the years studied

Year	Autumn			Winter			Spring			Summer		
	Prec (mm/sea.)	MT (°C)	RH (%)	Prec (mm/sea.)	MT (°C)	RH (%)	Prec (mm/sea.)	MT (°C)	RH (%)	Prec (mm/sea.)	MT (°C)	RH (%)
2007	49.96	24.28	78.21	64.41	22.27	80.70	13.07	24.10	69.11	29.94	25.09	70.31
2008	77.48	24.12	82.75	73.56	21.82	82.76	4.59	24.58	69.70	7.65	25.80	72.26
2009	50.91	24.77	79.89	37.74	22.77	80.49	13.84	24.76	69.92	37.09	25.59	76.62
2010	107.94	25.10	75.29	92.73	22.39	78.57	20.36	24.34	70.90	80.48	25.67	77.46
2011	121.15	23.89	81.54	72.03	21.73	82.94	12.46	24.02	73.25	39.15	25.36	74.24
2012	32.88	24.67	71.23	56.75	22.07	78.52	4.99	24.31	68.59	34.06	24.73	75.11
2013	68.47	24.51	78.08	55.74	22.31	80.59	10.97	24.48	72.10	15.85	25.78	71.89
2014	97.13	23.97	79.71	55.90	22.45	79.22	43.47	24.19	73.18	39.27	25.18	74.88
2015	49.84	24.98	73.71	42.67	22.59	77.74	17.78	24.96	68.57	9.95	25.36	74.85
2016	71.81	24.18	78.84	8.80	23.40	72.06	1.87	25.42	66.97	72.40	24.90	80.73
2017	72.08	24.99	76.88	78.67	22.07	84.06	11.52	24.12	71.94	10.03	25.88	72.50
Mean	72.70	24.50	77.83	58.09	22.35	79.79	14.08	24.48	70.38	34.17	25.40	74.62

* Prec (mm/sea.): Mean precipitation (mm/season); MT (°C): Mean temperature; RH (%): Mean Relative Humidity.

Description and analysis of data

No approval by the Ethics Committee for the Use of Animals was necessary for the purposes of this research, since all necessary information was obtained from existing databases.

Milk production and composition data and somatic cell count were obtained from monthly dairy monitoring reports in the selected herds. The data used were obtained from the official reports of the Dairy Herd Management Program of the Northeast (PROGENE) and the Association of Breeders of Pernambuco (ACP), with information according to the Brazilian Association of Cattle Breeders of the Holstein Breed (ABCBRH). Milk composition analyses, including lactose (LAC), fat (FAT), protein (PROT), total solids (TS) and non-fat solids (NFS), were performed using the infrared technique (Bentley 2000, Bentley Instruments, USA) and somatic cell count (SCC) using flow cytometry (Somacount 500, Bentley Instruments, USA).

The data were initially analyzed using the *R outlierKD* function to exclude extreme values (*outliers*) that could interfere with the results. SCC did not present a normal distribution and thus was transformed into a somatic cell score (SCS), resulting from logarithmic transformation obtained by equation $SCS = \log_2(CCS/100) + 3$. The SCS values corresponding to the SCC range from zero to 12,000 cells/ml were equated to zero to avoid negative numbers (Ribas et al., 2014).

Information from 380 cows was used for statistical analyses, with 6,311 records of milk production and 6,061 records for fat, protein, lactose, total solids, non-fatty solids (SNG) and somatic cell score (SCS), giving 42,677 data points. The effects of the farm (1, 2 and 3), order of calving (1, 2, 3 and ≥ 4), the seasons (autumn, winter, spring and summer) and calving year (2007 to 2017) were evaluated. The calving order ≥ 4 were grouped together due to low frequency of observations.

Variance analysis was performed using the general linear model procedure (PROC GLM) to determine the factors influencing the variables, followed by a comparison of means using the Tukey test at 5% probability.

The model used was:

$$Y_{ijkl} = \mu + Prop_i + Ord_j + Est_k + AP_l + (Ord*Est)_{jk} + e_{ijkl}$$

in which Y_{ijk} = observed value of the dependent variable (milk production, milk composition and SCS); μ = the overall mean; $Prop_i$ = effect of the farm; Ord_j = effect of the order of calving; Est_k = effect of season of the year; AP_l = effect of the year of calving; $Ord*Est_{jk}$ = effect of the interaction between calving order and season; and e_{ijkl} = random error associated with each observation.

Lactation curve

To define lactation curves according to the order of calving, the Wood model (1967) was used. This has been the most used mathematical function in studies involving the fitting of lactation curves of dairy cattle (Glória, Bergmann, Quirino, Ruas, & Pereira, 2010):

$$Y_t = at^b exp^{-ct}$$

in which Y is milk production (kg) in lactation time t (days); a, b and c are parameters that represent, respectively, the initial production of the cow, the average rate of increase in production until reaching the peak and the average rate of decline in production after reaching the peak of lactation; and *exp* is the basis of natural logarithm (constant = 2.7182). For this analysis, lactations with first records after 30 days of lactation, interval between weighing above 30 days and animals with less than four registered dairy records were excluded.

Aiming at the best fitting of curves, interval classes of 30 days were formed in lactation, using the average production of animals in these classes, the first class being composed of milk production measured between 5 and 30 days of lactation initiation and so on, up to the tenth class composed of lactation between 271 and 305 days of lactation. The analyses were performed using PROC NLIN of SAS 9.0. The production of milk at the peak $[(a*(b/c)^b)*exp-b]$, time until peak occurrence (b/c) and persistence of lactation $[-(b+1)*ln(c)]$ were also estimated.

Evaluation of reproductive indices

To evaluate the reproductive indices of the farms, the following parameters were evaluated: age at first calving (IPP), calving interval (IP) and service period (PS). The information obtained from zootechnical monitoring was tabulated to obtain IPP and IP data from the dates of parity and the duration of pregnancy (in days) for each animal, in order to standardize the main parameters used in the evaluation of reproductive performance in dairy cattle.

Data from cows with an IPP less than 570 and more than 1,020 days, IP less than 335 and more than 600 days and PS less than 50 days and more than 315 days were excluded, leaving 343 IPP entries and 290 entries for IP and PS, following the methodology proposed by Ferreira (1991). Variance analysis was performed using PROC GLM of SAS followed by a comparison of means using the Tukey test with 5% probability.

Results and Discussion

Table 2 presents the descriptive statistics for daily milk production, milk components, somatic cell score and reproductive characteristics analyzed in the present study.

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Table 2
Mean, minimum, maximum, standard-deviation (SD) and coefficient of variation (CV) of the characteristics of Holstein cows raised in the Agreste region of Pernambuco

Characteristics	N	Mean	Minimum	Maximum	SD	CV
Production						
PT (kg)	6311	32.46	10.30	61.00	8.15	25.12
Fat (%)	6061	3.33	1.50	6.05	0.75	22.60
Protein (%)	6061	3.21	2.00	4.99	0.39	12.19
Lactose (%)	6061	4.58	3.31	5.20	0.23	5.00
Total solids (%)	6061	12.12	9.52	15.19	0.94	7.77
SNG (%)	6061	8.78	6.46	10.13	0.44	4.99
SCS	6061	3.87	0.00	9.64	2.40	62.01
Reproduction						
IPP (days)	343	771.60	570.00	990.00	91.75	11.89
IP (days)	290	453.57	335.00	600.00	75.35	16.61
PS (days)	290	168.57	50.00	315.00	75.35	44.70

*PT: Total production per day; SNG: Non-fat solids; SCS: Score of somatic cells; IPP: age at first calving; IP: Calving interval; PS: period service.

The Holstein cows raised in the semiarid region in northeast Brazil produced good levels of milk (average 32.46 kg/cow/day), resulting from adaptations to food management conditions and improvements made in cows' comfort.

Lower levels of production were found for Holstein cows raised in other Brazilian regions. In the southern region, for instance, Silva et al. (2011), Ludovico et al. (2015) and Bondan et al. (2018) found an average production of 28.62, 31.78 and 25.50 kg/cow/day, respectively. In the southeast region, Bignardi et al. (2015) and Villadiego et al. (2016) recorded an average value of 24.25 and 22.9 kg/cow/day, respectively. In countries such as the United States and Canada, these values were considerably higher, as demonstrated by Stoop, Thompson-Crispi, Cartwright and Mallard (2016) and García-Muñoz, Singh, Leonardi and Silva-Del-Río (2017), where average daily productivity was 36.68 and 39.78 kg/day, respectively, demonstrating the difference in milk production in more specialized countries, where technologies and selection programs have been in use for some time.

Regarding milk components, the mean percentages of fat, protein, lactose and total solids were 3.33%, 3.21%, 4.58% and 12.12%, respectively (Table 2). The mean somatic cell score was 3.87, corresponding to 185,000 cells/ml.

Bondan et al. (2018) evaluated the composition of milk and somatic cells (SCC) using 148,604 records from herds of Holstein cows in southern Brazil and found an average of 3.45% fat, 3.23% protein, 4.45% lactose, and a SCC of 5.22. Except for lactose, these values were higher than those found in the current study.

The effect of the interaction between calving order and season of the year was significant ($p < 0.05$) for milk production, lactose content and SCS. Milk production was higher in spring in all parity orders, with an increase in production as the order of parity increased: first-order animals produced 31.54 kg and those of $\geq$ 4th order 35.75 kg, representing an increase of 13.35%. The increase in milk production in multiparous cows may have been a reflection mainly of the higher productive capacity of animals when they reached adulthood,

with body development and the breast gland already established. Likewise, spring is a dry period with food shortages, when it is necessary to use food supplementation management practices, and this may have been a relevant factor for the increase in milk production with reduced solids content as reported in other studies (Magalhães et al., 2006; Yang, Yang, Yi, Pang, & Xiong, 2013; Vijayakumar et al., 2017; Bondan et al., 2018).

On the other hand, the total milk solids content was higher in autumn and declined with the order of parity. This pattern may reflect the lower amount of milk produced in autumn, a behavior known as the dilution effect, because the higher the production of milk the lower the solid components (Mollenhorst, Hidayat, Broek, Neijenhuis, & Hogeveenet, 2011). The lactose content showed a similar pattern to that of the total solids.

Regarding SCS, cows of the 3rd and ≥ 4th order of parity presented higher somatic cell scores in winter (SCS ranging from 4.91 to 5.20), while the

1st order cows presented the lowest values in spring (SCS=3.00). Multiparous cows usually produce milk with a larger number of somatic cells, which is mainly associated with their increased exposure to factors that are sources of infection, which can be potentiated in the winter period, during which health care rates are affected and, consequently, the incidence of mastitis cases increases (Bondan et al., 2018).

There was an effect ($p< 0.05$) of the farms on the production values, milk composition and SCS, but not protein (Table 3). Animals from farm 2 performed better in terms of milk production and components (lactose, fat, total solids and SNG) and a lower SCS, probably reflecting better daily management, better housing conditions, and a high rate of replacement of cows (30%) aimed at the selection of animals to increase milk production. Good practices in milk production are fundamental at all stages, providing quality and safety assurance as well as adding value to the food production system (Ribeiro, Tamanini, Corrêa da Silva, & Beloti, 2015).

Table 3
Effect of the farm on the productivity and milk composition of Holstein cows raised in the Agreste region of Pernambuco

Variable/Farm	1		2		3		P-value
	N	Mean ± SD	N	Mean ± SD	N	Mean ± SD	
PT (kg)	1512	33.40 ± 8.77 b	901	36.69 ± 8.10 a	3898	31.12 ± 7.5 c	<0.001
Fat (%)	1430	3.02 ± 0.80 c	886	3.75 ± 0.64 a	3745	3.35 ± 0.70 b	<0.001
Protein (%)	1430	3.20 ± 0.41	886	3.20 ± 0.32	3745	3.21 ± 0.40	0.6424
Lactose (%)	1430	4.59 ± 0.22 b	886	4.71 ± 0.16 a	3745	4.55 ± 0.23 c	<0.001
Total solids (%)	1430	11.78 ± 0.90 c	886	12.69 ± 0.81 a	3745	12.12 ± 0.92 b	<0.001
SNG (%)	1430	8.76 ± 0.43 b	886	8.94 ± 0.39 a	3745	8.76 ± 0.44 b	<0.001
SCS	1430	4.10 ± 2.47 a	886	3.06 ± 2.04 b	3745	3.98 ± 2.41 a	<0.001

*PT: Total production per day; SNG Non-fat solids; SCS: Score of somatic cells. Means followed by the same letter on the line do not differ from each other by Tukey test ($P < 0.05$).

There was an effect of the order of parity on the production and composition of milk and SCS (Table 4). The cows of the 2nd, 3rd and ≥ 4th order presented the highest levels of milk production, with no difference ($p > 0.05$) between them, followed by

1st order cows (25.55 ± 2.84 months), which were the least productive. Yang et al. (2013) and Bondan et al. (2018) claim that primiparous cows produce less milk, while animals reach their peak production at 59-71 months old, decreasing after 7 years of age.

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The high production observed in 3rd and 4th order cows is related to the development and increase in udder size, resulting directly in an increased number of secretory cells (Sorensen, Norgaard, Theil, Vestergaard, & Sejrsen, 2006), as well as body development and the relationship of control in the mobilization of lipid reserves between primiparous and multiparous cows, which directly reflect on the increase in milk production (Vijayakumar et al., 2017).

Table 4
Effect of the order of calving on the productivity and milk composition of Holstein cows raised in the Agreste region of Pernambuco

Variable/Order	1st		2nd		3rd		≥4th		P-value
	N	Mean ± SD	N	Mean ± SD	N	Mean ± SD	N	Mean ± SD	
PT (kg)	2745	30.42 ± 7.60 b	1763	33.68 ± 8.53 a	1133	34.38 ± 7.90 a	670	34.38 ± 7.82 a	<0.001
Fat (%)	2635	3.37 ± 0.74 a	1705	3.34 ± 0.75 ab	1090	3.26 ± 0.74 b	631	3.27 ± 0.82 b	0.0171
Protein (%)	2635	3.21 ± 0.38 b	1705	3.25 ± 0.40 a	1090	3.17 ± 0.38 c	631	3.14 ± 0.41 c	<0.001
Lactose (%)	2635	4.65 ± 0.20 a	1705	4.56 ± 0.21 b	1090	4.51 ± 0.24 c	631	4.46 ± 0.23 d	<0.001
Total solids (%)	2635	12.24 ± 0.91 a	1705	12.15 ± 0.94 b	1090	11.95 ± 0.92 c	631	11.85 ± 1.06 c	<0.001
SNG (%)	2635	8.87 ± 0.42 a	1705	8.81 ± 0.41 b	1090	8.68 ± 0.42 c	631	8.56 ± 0.46 d	<0.001
SCS	2635	3.24 ± 2.15 c	1705	4.04 ± 2.47 b	1090	4.64 ± 2.41 a	631	4.76 ± 2.49 a	<0.001

*PT: Total production per day; SNG: Non-fat solids; SCS: Score of somatic cells. Means followed by the same letter on the line do not differ from each other by Tukey test (P < 0,05).

There was a significant increase in SCS as the order of calving increased. Similar results were observed by other authors in Holstein cows in Brazil (Magalhães et al., 2006; Dal Pizzol, Thaler, Farias, Braun, & Werncke, 2014) and China (Zhao et al., 2015). The lowest values were observed for the 1st calving order, possibly due to lower exposure of the animal to infectious agents causing mastitis (Souza et al., 2010). As the order of calving increases, which also coincides with increasing age and milk production, animals become more susceptible to and are exposed more frequently to infection (Dal Pizzol et al., 2014). According to Cunha et al. (2008), the increase in SCS in the milk of older cows could be partially justified by the increase in breast gland scaling epithelial cells present in the milk of multiparous cows.

The percentages of milk components varied with the number of lactations (Table 4). The component with higher value in the 2nd lactation was protein (3.25%) and similar result was found by Souza et al. (2010). Bondan et al. (2018) cited various factors affecting protein content, including that cows of 1st and 2nd calving order produce milk with a higher protein content than cows that have had more offspring. For the other components (fat, lactose, total solids and non-fatty solids), the highest values were observed in the 1st lactation, and all values declined as the number of lactations increased.

The above results corroborate the results obtained by Cunha et al. (2008) who studied the characteristics of cows that are part of the dairy monitoring program of the Association of Holstein Cattle Breeders of Minas Gerais, and by Galvão et al. (2010), who evaluated the influence of milk production and the order of calving on the physicochemical composition of milk of zebu cows.

The seasons significantly influenced the production and composition of milk and SCS (P< 0.05) (Table 5). Higher average daily production

(33.91 kg/cow/day) and a lower fat (3.30%) and protein content (3.15%) were observed in spring, a period that is generally considered dry (14.08 mm) and has an average temperature around 24.5 °C (Table 1). In the region under study there is a tendency for breeders to provide better nutritional management of animals in the dry season, since this period coincides with a reduction in the supply of forage in the region, leading to the use of a higher proportion of concentrate. In this way, the animals respond with an increase in milk production and decreased total solids content during this as demonstrated by Magalhães et al. (2006) in Holstein cows raised in the state of São Paulo in the dry months with food supplementation.

Table 5
Effect of the season on the productivity and milk composition of Holstein cows raised in the Agreste region of Pernambuco

Variable/Season	Autumn		Winter		Spring		Summer		P-value
	N	Mean ± SD	N	Mean ± SD	N	Mean ± SD	N	Mean ±SD	
PT (kg)	1475	30.93 ± 7.93 c	1620	32.67 ± 8.34 b	1720	33.91 ± 8.05 a	1496	32.10 ± 7.99 b	<0.001
Fat (%)	1422	3.39 ± 0.77 a	1578	3.28 ± 0.73 b	1590	3.30 ± 0.76 b	1471	3.37 ± 0.75 a	<0.001
Protein (%)	1422	3.25 ± 0.43 a	1578	3.18 ± 0.39 b	1590	3.15 ± 0.36 b	1471	3.25 ± 0.37 a	<0.001
Lactose (%)	1422	4.56 ± 0.24 b	1578	4.58 ± 0.23 b	1590	4.61 ± 0.21 a	1471	4.57 ± 0.23 b	<0.001
Total solids (%)	1422	12.17 ± 0.95 a	1578	12.06 ± 0.93 b	1590	12.08 ± 0.94 b	1471	12.18 ± 0.94 a	<0.001
SNG (%)	1422	8.77 ± 0.49	1578	8.78 ± 0.42	1590	8.78 ± 0.40	1471	8.81 ± 0.44	0.0513
SCS	1422	3.92 ± 2.40 a	1578	3.98 ± 2.45 a	1590	3.59 ± 2.41 b	1471	4.03 ± 2.32 a	<0.001

*PT: Total production per day; SNG: Non-fat solids; SCS: Score of somatic cells. Means followed by the same letter on the line do not differ from each other by Tukey test (P < 0,05).

Spring was also the season with the highest lactose concentration (4.61%). This is directly related to the higher amount of milk produced in this season. The highest SCS (4.03) was observed in the summer, a period with a higher average temperature (25.4 °C) and high humidity (74.62%), and the lowest SCS (3.59) was observed in spring. Similar results were observed by Henrichs, Macedo and Karam (2014), who found that the mean somatic cell score was lower in winter and spring, and higher in summer and autumn. The increase in temperature and humidity that occurs in summer leads to higher thermal stress and lower responsiveness, favoring the incidence of infection in these months (Lambertz, Sanker, & Gauly, 2014).

Milk production was affected by the year of delivery: between 2007 and 2011 milk production decreased progressively, however between 2014 and 2017 milk production increased, highlighting 2017, which increased by 6.1 kg compared to year 2007 (Table 6). The fat, lactose and total solids contents were also affected by the year, gradually increasing to the highest levels in 2016 and 2017. The protein content showed the opposite behavior, being higher in the early years of the study. The SCS was also affected by the year; the lowest scores were in 2007, 2010 and 2017.

Table 6
Effect of the year of calving on the productivity and milk composition of Holstein cows raised in the Agreste region of Pernambuco

Year/ Variable	PT (kg)	Fat (%)	Protein (%)	Lactose (%)	Total solids (%)	SCS
2007	29.09 ± 8.94 e	3.23 ± 0.83 cd	3.29 ± 0.43 ab	4.53 ± 0.27 c	12 ± 0.86 cd	3.43 ± 2.63 df
2008	29.49 ± 8.84 e	2.84 ± 0.71 f	3.32 ± 0.39 ab	4.55 ± 0.21 bc	11.62 ± 0.78 e	4.93 ± 2.26 a
2009	32.41 ± 8.46 d	3.23 ± 0.81 cd	3.06 ± 0.38 e	4.59 ± 0.25 b	11.78 ± 0.86 de	4.85 ± 2.29 a
2010	25.74 ± 9.15 f	3.45 ± 0.73 b	3.37 ± 0.39 a	4.56 ± 0.21 bc	12.32 ± 0.91 b	3.29 ± 2.26 ef
2011	28.1 ± 7.5 e	3.51 ± 0.66 b	3.26 ± 0.42 b	4.55 ± 0.22 bc	12.31 ± 0.94 b	3.21 ± 2.18 f
2012	32.08 ± 7.57 d	3.29 ± 0.68 c	3.28 ± 0.43 b	4.52 ± 0.24 c	12.09 ± 0.85 c	4.04 ± 2.44 bc
2013	32.42 ± 7.36 d	2.96 ± 0.72 f	3.25 ± 0.4 bc	4.54 ± 0.25 c	11.76 ± 0.85 de	4.42 ± 2.5 ab
2014	34.02 ± 8.04 bc	3.04 ± 0.68 ef	3.12 ± 0.37 e	4.59 ± 0.23 b	11.76 ± 0.88 de	4.03 ± 2.32 bc
2015	33.15 ± 7.91 cd	3.14 ± 0.75 de	3.15 ± 0.36 de	4.59 ± 0.23 b	11.89 ± 0.97 de	3.88 ± 2.62 cd
2016	34.43 ± 7.22 ab	3.65 ± 0.69 a	3.17 ± 0.34 de	4.64 ± 0.2 a	12.47 ± 0.88 ab	3.97 ± 2.27 cd
2017	35.1 ± 7.07 a	3.7 ± 0.67 a	3.19 ± 0.37 cd	4.63 ± 0.21 a	12.54 ± 0.89 a	3.6 ± 2.27 de
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

*PT: Total production per day; SCS: Score of somatic cells. Means followed by the same letter on the line do not differ from each other by Tukey test (P < 0.05).

The increase in productive indices in recent years can be attributed to improvements in herd productivity, resulting from changes in production systems, the genetic potential of the animals and increasingly efficient diets. The variation in SCS over the years indicates that farmers need to maintain effective management practices for the prevention and control of clinical and subclinical mastitis for better quality milk production. Ribeiro, Tinoco, Lima, Guilhermino and Rangel (2009) stated that any increase in the production, productivity and reproductive efficiency of dairy cows depends on improvements in the environment, nutrition, health and animal welfare, providing the expression of the genetic potential of animals

Regarding the lactation curves estimated for calving orders using the Wood model, the authors observed a similar shape to the observed curve, demonstrating that the model used a good fit to the data, with an ascending phase to the peak and a descending phase after the peak (Figure 1), as also found by Lazzari et al. (2013), who evaluated mathematical models for the lactation curve of Holstein cows in the state of Santa Catarina, Brazil. These researchers also opted for Wood's model, because it has a lower index, lower residual deviations, and better graphic representation in comparison to other studied models.

Initial production (parameter a), the rate of production increase until peaking (parameter b), the rate of decline in production after peak (parameter c) and production at peak increased with order of parity (Table 6). Production was lowest in the first order of calving, but the duration of lactation was longer, giving the curve a steeper decline. Lactation duration is economically the parameter of greatest importance in the curve, being related to cost reduction and the lower occurrence of metabolic disorders and reproductive problems (Jakobsen et al., 2002).
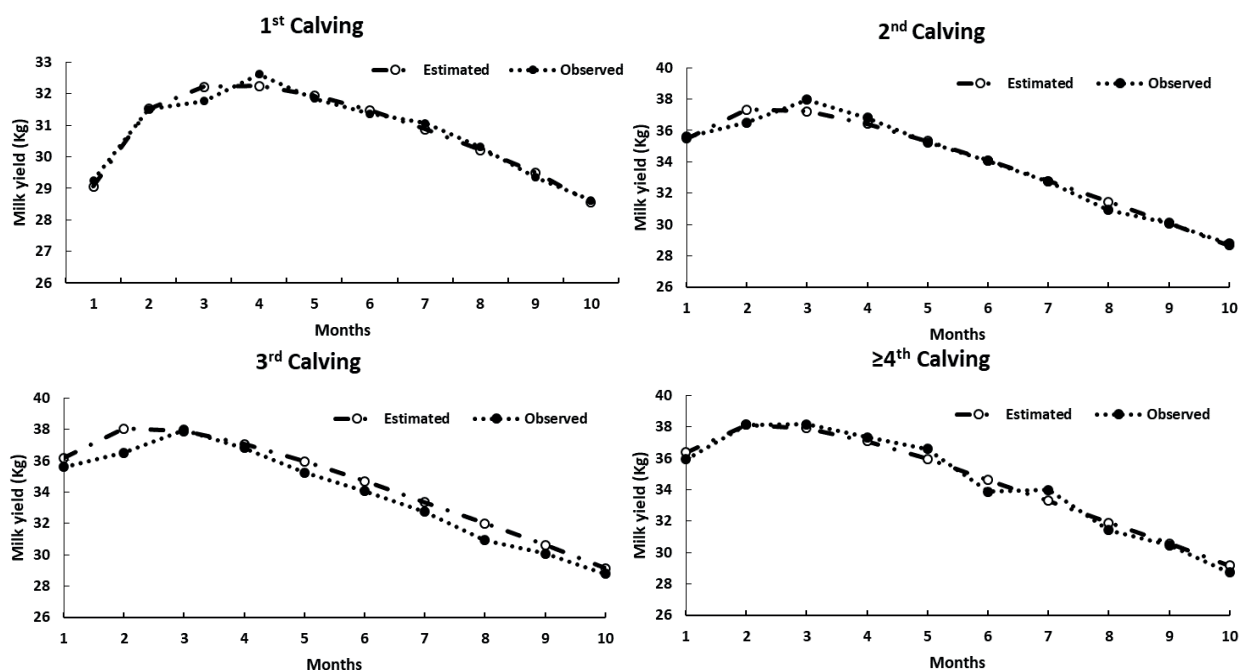
Figure 1. Lactation curves obtained by means of milk yield observed and estimated using the Wood model for each calving order and months of lactation.

Third- and fourth-order cows were the most productive, reaching peak production most rapidly (Table 7). According to Souza et al. (2010), primiparous cows are still in the body growth phase and the mammary gland is not yet fully developed, resulting in lower productive capacity and longer time to peak. It is estimated that Holstein cows from the second lactation have a higher production value at peak and higher total production during lactation, because these characteristics are directly correlated, resulting from the development of the mammary gland and larger body size (Noro, González, Campos, & Dürr, 2006).

Table 7
Lactation curve parameters, peak production, peak time and lactation persistence estimated using the Wood model for each calving order analyzed

	1º Calving	2º Calving	3º Calving	≥4º Calving
Parameter a	21.4391	27.5042	28.3199	28.6314
Parameter b	0.1168	0.103	0.1000	0.0979
Parameter c	0.00128	0.00188	0.00186	0.00187
Production at peak (kg)	32.9604	37.6976	38.28	38.27879
Peak time (days)	91.25	54.78723	53.76344	52.35294
Persistence	3.23067	3.0066	3.00354	2.995245

a = Initial cow production; b = production increase rate until it reaches peak; c = decline in production after reaching peak production.

Coelho, Barbosa, Tonhati and Freitas (2009) identified the IPP as one of the most important characteristics for reproductive performance, affecting directly throughout its productive life, thus impacting on dairy profitability. The IPP in the present study did not differ ($P > 0.05$) between the three farms, with averages like 771.6 ($\pm$92.8) days of age (Table 8). This IPP value was higher than that considered ideal for the breed under study. Cooke, Cheng, Bourne and Wathes (2013) recommended an age at first parity of 720 days for the Holstein breed, to ensure better use of the productive life of the animal. Eastham et al. (2018) stated that the ideal goal for the breed is rarely achieved in any country and that the average IPP ranges from 735 to 930 days. Almeida et al. (2017) evaluated data from the Brazilian Association of Breeders of Cattle of the Holstein Breed and its state affiliates, between 1995 and 2010, and reported that the average IPP in the herd was 805.8 days.

Table 8
Mean values and standard deviation of characteristics: age at first calving, calving interval and service period of Holstein cows

Farm	Variable					
	N	IPP (days)	N	IP (days)	N	PS (days)
1	112	767.4 ($\pm$93.3) a	71	454.0 ($\pm$81.2) a	71	169.0 ($\pm$81.2) a
2	62	773.7 ($\pm$95.1) a	60	420.0 ($\pm$66.4) b	60	135.0 ($\pm$66.4) b
3	169	773.6 ($\pm$90.2) a	159	459.8 ($\pm$72.7) a	159	174.8 ($\pm$72.7) a
Mean		771.57		444.57		159.56

* Means followed by distinct letters in the column differ by Tukey test at the level of 5% significance.

Parity interval (IP) and service period (PS) showed significant differences between farms ($P< 0.05$). Farm 2 presented the lowest values (420 and 135 days for IP and PS, respectively), while the other two farms were closer to the mean values (Table 8). The values found for IP and PS were higher than those reported by other researchers. Grebogi et al. (2008) and Almeida et al. (2017) found mean values of 390 and 110, and 420 and 61 days, for IP and PS respectively. However, they were like those found by Marestone et al. (2013), who reported mean values of 449 ($\pm$118.2) and 178 ($\pm$118.73) days for Holstein cows in the states of São Paulo and Paraná, respectively. Such values are considered high for animals of this breed, in which the recommended values are approximately 365 days for IP and approximately 90 days for PS (Bahonar, Azizzadeh, Stevenson, Vojgani, & Mahmouudi, 2009). Longer intervals, above 420 days, are related to decreased milk production and increased reproductive problems such as abortion (Kashoma, Mwingira, Werema, & Kessy, 2015).

Conclusion

Order of calving, farm, season and year of calving, as well as the interaction between order of calving and season of the year are important factors and should be considered in studies with the objective of evaluating the production and quality of milk from cows bred for high levels of production and grown in semi-arid regions. In addition, the farm effect is a determining factor in the evaluation of reproductive indices such as parity interval and service period.

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