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Fertility and hair coat characteristics of Holstein cows in a tropical environment

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Abstract

This experiment deals with the effects of hair coat on the number of inseminations per conception in Brazilian Holstein cows. Data (n = 2446) were collected from 939 primiparous and multiparous Holstein cows in a commercial herd managed under an intensive free-stall system and provided with cooling units (fans and sprinklers). The following hair coat characteristics were considered: hair length, coat thickness, hair diameter, coat color (proportion of black hairs), and the number of hairs per unit area. Low correlation values were observed between inseminations/conception and the following hair coat characteristics: coat color (r = -0.06), coat thickness (r = 0.07), number of hairs (r = -0.06), and hair diameter (r = -0.04). Analysis of variance showed significant effects of year, age, parity, dams' sire within country of origin, and coat thickness. Cows with coats less than 2 mm thick had a lower ($P < 0.05$) number of inseminations/conception (2.4 ± 1.8) than those with more than 3 mm thickness (2.7 ± 2.1 inseminations/conception). It was concluded that a thick hair coat is associated with a reduced conception rate in Holstein cows in tropical environments because of chronic, high heat stress.

Keywords: adaptation; conception; hair coat; Holstein cows; insemination number.

Introduction

Reproductive efficiency of dairy cows is greatly affected by elevated environmental temperature and humidity (Gwazdauskas *et al*., 1973; Thatcher, 1974; Turner, 1982; Badinga *et al*., 1985; Her *et al*., 1988; Hansen, 1992; de la Sota *et al*., 1998; Wolfenson *et al*., 2000; Rivera and Hansen, 2001; Roth *et al*., 2001). Summer conditions are severe enough to lower conception rate (Thatcher, 1974; Ingrahan *et al*., 1975; Badinga *et al*., 1985; Cavestany *et al*., 1985; Putney *et al*., 1989; Drost *et al*., 1999). If the body temperature of a female rises, there is evidence of damage to: (1) the spermatozoa, while capacitating in the female tract (Howarth *et al*., 1965; Monterroso *et al*., 1995; Hansen *et al*., 2001); (2) the oocyte, before (Edwards and Hansen, 1997; Rivera and Hansen, 2001; Roth *et al*., 2001) or after ovulation (Ryan *et al*., 1993; Edwards and Hansen, 1996; Sartori *et al*., 2002); (3) the embryo, during early cleavages (Gordon *et al*., 1987; Putney *et al*., 1988; Putney *et al*., 1989; Edwards and Hansen, 1997; Sartori *et al*., 2002); and (4) fetal growth, during the middle and last third of gestation (Hoopkins *et al*., 1980; Biggers *et al*., 1987). Also, high environmental temperatures negatively affect the semen quality of bulls (Cassady *et al*., 1953; Milicevic *et al*., 1968; Silva and Casagrande, 1976).

The relationship between reproductive efficiency and heat stress in dairy cows has been well established (Wolfenson *et al*., 2000), but the problem remains of how to minimize the effects of the heat stress on reproduction. One of the possibilities for practical consideration is the genetic selection of Holstein cattle for a more appropriate hair coat for hot and humid environments. Information about the relationships between hair coat type and reproductive performance is limited, especially for Brazilian Holstein cattle, which mostly originate from imported genotypes. Such information is needed in order to understand the response of the animal to its environment and to evaluate reproductive problems as a result of severe heat stress.

Hair coat characteristics affect the transfer of thermal energy from the skin to the environment and consequently, body temperature control (Cena and Monteith, 1975a; b; McArthur, 1991; Silva, 1999). When an animal is exposed to the sun, an extremely steep temperature gradient is established between the hair coat surface and the skin. A short, sleek, thin coat improves heat and water vapor conductance through the coat layer in stressful hot and humid environments (Gebremedhin *et al*., 1997; Turnpenny *et al*., 2000). Therefore, genetic progress towards a hair coat, appropriate for hot and humid environments, could be a strategy to enhance reproductive function of Holstein cows in Brazil and elsewhere. The present study evaluated the effects of hair coat characteristics on the reproductive performance of Holstein cows in a tropical environment.

Materials and Methods

Animals, management and data source

Data from 2446 inseminations were obtained from 939 Holstein cows of a commercial dairy herd located in Descalvado, State of São Paulo, Brazil (21º 57´ 42´´ South, 47º 50´ 28´´ West, 860 m high). Data from pregnant and non-lactating heifers and first

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lactation and greater cows were analyzed. Animal age was from 2 to 13 years, and were daughters of 208 sires from the USA, Canada, and Brazil. They were housed in an intensive free stall, large-scale system provided with cooling units (fans and sprinklers).

Estrus detection was done by visual observation of cows in the early morning, and the animals were inseminated in the afternoon. They were bred at the first estrus detected after 60 days postpartum. Pregnancy diagnosis was performed by rectal examination at 45 days after insemination. Individual records included cow identification number, birth date, sire and dam identifications, insemination and calving dates, and the number of inseminations per conception (IPC) for all parities during the period from 1991 to 2000.

Morphological characteristics of the coat

Measurements of coat thickness (mm) and percentage of black coat color (%) were carried out from November 2000 to April 2001 and hair sampling as well. The percentage of black color relative to whole body surface area was estimated by visual inspection of both sides of each animal, except the tail, legs, and belly regions, according to the method of Becerril and Wilcox (1992). Coat thickness was measured in the center of the thorax of each animal about 20 cm below dorsal line, by using a thin metal ruler. Hair samples were taken from the same region where coat thickness was measured using electrician's pliers adapted in such a way that all the hairs in an 18 mm^2 area could be plucked out (Silva *et al*., 1988; Silva, 2000a). Hair samples were stored in plastic envelopes and measurements (hair length, number of hairs per unit area, and hair diameter) were done later in the laboratory.

The average hair length (mm) of each sample was calculated from the 10 longest hairs of the sample, according to the method of Udo (1978). Each sample had about 150–400 hairs. The number of hairs per unit area (hairs/cm^2) was obtained by direct counting of all hairs present in the sample. A Mitutoyo digital micrometer was used to measure hair diameter (µm) of the same hairs used for length measurement.

Statistical analyses

Data were analyzed by the least squares method according to Littel *et al*. (1991). Data for the number of IPC were not normally distributed. Thus, data were transformed by a power scale prior to analysis (Freeman and Tukey, 1950). The mathematical model used to analyze data of the number of IPC was the following:

$$Y_{ijklmnopqrst} = \alpha + a_i + m_{ij} + i_k + p_l + s_{lm} + o_n + c_o + t_p + l_q + n_r + d_s + \epsilon_{ijklmnopqrst}$$

Where, $Y_{ijklmnopqrst}$ was the number of IPC in the t-th cow; a_i the effect of the i-th year of insemination class (I = 1,..., 7; where, 1 = 1991 to 1994; 2 = 1995; 3 = 1996; 4 = 1997; 5 = 1998; 6 = 1999 and 7 = 2000); m_{ij} the effect of j-th month within i-th year (j = 1,..., 76); i_k the linear and quadratic effect of age at insemination; p_l the random effect of l-th sire origin (l = 1,..., 3; where, 1 = Brazil, 2 = Canada, 3 = USA); s_{lm} the effect of m-th sire within l-th origin (m = 1, ..., 208); o_n the effect of n-th parity class (n = 1, ..., 6; where, 1 = one, 2 = two; 3 = three, 4 = four, 5 = five, 6 = more than five parities); c_o the effect of o-th coat color class (o = 1, ..., 3; where, 1 ≤ 30%, 2 = 30-70%, 3 ≥ 70% of black hairs); t_p the effect of p-th hair coat thickness class (p = 1, ..., 3; where, 1 = 2 < mm, 2 = 2-3 mm, 3 ≥ 3 mm); l_q the effect of q-th the hair length class (q = 1, ..., 3; where, 1 ≤ 10 mm, 2 = 10-15 mm, 3 ≥ 15 mm); n_r the effect of r-th number of hairs per unit area class (r = 1,..., 3; where, 1 ≤ 800 hairs/cm^2, 2 = 800-1200 hairs/cm^2, 3 ≥ 1200 hairs/cm^2); d_s the effect of s-th hair diameter class (s = 1,..., 3; where, 1 ≤ 55 µm, 2 = 55-65 µm, 3 ≥ 65 µm), $\varepsilon_{ijklmnopqrst}$ the random error, and α is the intercept.

Results

The overall mean and standard error of the number of IPC, grouped by hair coat characteristics, are shown in Table 1. With respect to the hair coat characteristics, the overall means showed that the cows had a large proportion of black hairs and had a thin coat with short, thick hairs.

Table 2 depicts correlations between hair coat characteristics and the IPC. Significant (P < 0.05) correlation values were reported for coat color, hair thickness, number of hairs per unit area, and hair diameter, but not for hair length. There were low correlations (lower than r = 0.06) between these traits.

The analysis of variance of IPC (Table 3) showed significant (P < 0.01) variation for the year of insemination, parity, sire within origin, linear and quadratic age of cows, and hair coat thickness. It is interesting to note that high values of mean squares (Table 3) of linear and quadratic age and parity (131.329; 69.9348 and 28.0227, respectively) showed that these effects were responsible for almost the total variation for the number of IPC.

Table 4 shows the least-squares means of IPC according to year of insemination, dams' sire within country of origin, parity, and coat characteristics. In general, heifers had lower number of IPC (1.87) in comparison to the other categories of parity; multiparous cows with more than five calvings were less likely to conceive than other cows. The number of inseminations per conception increased from 1.86 in 1991-1994 to 2.57-3.06 from 1998-2000 probably because of environmental and management alterations during these years, mainly the intensification of the production system and the increasing of milk production.

The origin of the dam's sire was not significant (P > 0.05), but the sire-within-origin effect was a significant ($P < 0.01$) source of variation for the number of IPC (Table 3). A comparison of the IPC according to sires from Canada, the USA, and Brazil is shown (Table 4). Daughters of Canadian and American bulls had lower a number of IPC (2.53 and 2.50, respectively) than the cows sired by Brazilian bulls (2.96). However, these differences were not statistically significant ($P > 0.05$).

With respect to the coat type, hair thickness significantly ($P < 0.01$) affected the number of IPC. The lowest number of IPC was observed in cows with a thin coat layer (< 2 mm) that significantly differed from cows with a thicker coat (> 3 mm), as shown in Table 4. It must be emphasized that the cows used in the present study had an overall hair thickness of 2.48 mm (Table 1). The hair length, diameter, and density did not affect the number of IPC. As expected, however, least squares means (Table 4) indicated that a lower number of IPC was observed for cows and heifers with shorter, denser, thicker hairs.

Table 1. Overall means, standard error, maximum and minimum values of hair coat characteristics, and number of inseminations per conception in Holstein cows located in Descalvado, SP, Brazil.

Traits	Overall means (n)	Standard error	Range	
			Maximum	Minimum
C (%) [a]	70.22 (939)	29.01	100	0
T (mm) [b]	2.48 (939)	0.48	5.3	1.5
L (mm) [b]	12.60 (939)	3.45	29.3	3.84
N (hair/cm^2) [b]	987.00 (939)	374.00	3545.0	221.00
D (μm) [b]	62.49 (939)	5.60	97.7	44.06
IPC (unit.)	2.79 (2446)	2.47	12.0	1.00

Coat color, C; hair coat thickness, T; hair length, L; number of hairs per unit area, N; hair diameter, D; number of inseminations per conception, IPC.
[a]Percentage of black coat color relative to body surface area.
[b]Values correspond to average, regardless of coat color; (n) is the number of observations.

Table 2. Correlation coefficients between hair coat characteristics and number of inseminations per conception from 2446 inseminations in 939 Holstein cows in a tropical environment.

Characteristics	Correlation Coefficient	P-Value
Coat color	-0.0595	0.0035**
Hair coat thickness	0.0653	0.0013**
Hair length	0.0164	0.4205^{NS}
Number of hairs per unit area	- 0.0578	0.0045**
Hair diameter	- 0.0443	0.0296**

** $P < 0.01$; ^{NS} $P>0.05$.

Table 3. Analysis of variance for the number of inseminations per conception (IPC) in Holstein cows in tropical environment.

Variation source	d.f.	Mean Squares	P-Value
Year	6	1.3622	0.0001**
Month within year	75	0.1451	0.9342^{NS}
Parturition	5	28.0227	0.0001**
Origin	2	0.4183	0.1111^{NS}
Sire within origin	207	0.3042	0.0001**
Linear age	1	131.3294	0.0001**
Quadratic age	1	69.9348	0.0001**
Coat color	2	0.4049	0.3451^{NS}
Hair coat thickness	2	1.5849	0.0156**
Hair length	2	0.1210	0.7275^{NS}
Number of hairs per unit area	2	0.4961	0.2716^{NS}
Hair diameter	2	0.4280	0.3248^{NS}
Error	2138	0.1902	
R^2		0.4703	
Coefficient of Variation		29.0376	

**$P < 0.01$; ^{NS} $P>0.05$;

Table 4. Least-squares means of the number of inseminations per conception (IPC) in Holstein cows in a tropical environment according to year of insemination, origin of cows' sires, parity, coat color, hair thickness, diameter, length, and number of hairs per unit area.

Effects	n	IPC ± SD
Year of the insemination		
1991 to 1994	135	1.86 ± 1.25 d
1995	128	1.94 ± 1.26 cd
1996	199	2.33 ± 2.01 ab
1997	324	2.34 ± 1.78 c
1998	482	3.06 ± 2.41 ab
1999	772	2.57 ± 2.01 ab
2000	429	2.72 ± 2.02 ab
Origin of sire		
Brazil	329	2.96 ± 2.35 a
Canada	403	2.53 ± 1.92 a
United States	1737	2.50 ± 1.98 a
Parity		
1	982	1.87 ± 1.37 e
2	646	2.68 ± 2.11 e
3	408	3.35 ± 2.28 b
4	223	3.23 ± 2.41 c
5	121	2.97 ± 2.16 d
>5	89	3.65 ± 2.50 a
Coat color		
< 30 %	414	2.75 ± 2.07 a
30-70 %	605	2.66 ± 2.22 a
> 70 %	1461	2.48 ± 1.93 a
Hair coat thickness		
< 2 mm	325	2.40 ± 1.84 b
2-3 mm	1903	2.58 ± 2.04 ab
> 3 mm	252	2.74 ± 2.18 a
Hair length		
< 10 mm	652	2.56 ± 1.98 a
10-15 mm	1306	2.56 ± 2.04 a
> 15 mm	522	2.61 ± 2.07 a
Hair density		
< 800 hairs/cm^2	825	2.59 ± 2.00 a
800-1200 hairs/cm^2	1044	2.65 ± 2.10 a
> 1200 hairs/cm^2	611	2.40 ± 1.94 a
Hair diameter		
< 55 µm	329	2.65 ± 2.01 a
55-65 µm	1459	2.62 ± 2.11 a
> 65 µm	692	2.43 ± 1.85 a

Means within category with the same superscript for each effect do not differ statistically by Tukey's test (P> 0.05; n =number of observations; SD=standard deviation).

Discussion

Low fertility in dairy cattle is closely associated with heat stress during the hot season in temperate and subtropical areas. During seasonal periods of heat stress, pregnancy rates decline as a result of decreased conception rates (Thatcher and Collier, 1986) and lowered rates of estrus detection (Her *et al.*, 1988). In Florida, conception rates of lactating cows decreased from 48 % in March to 18 % in July and did not recover until November (Badinga *et al*., 1985). As expected, the present results did not present significant differences in the number of IPC among the months of the year due to the small amount of variation in maximal air temperature during the summer and winter in tropical conditions compared to temperate climates. An appropriate hair coat improves fertility in high production Holstein cows in hot, humid environments as the results of this research clearly showed.

The observed average number of IPC was higher than the values 1.9, 1.9, and 1.5 reported for Holsteins by Badinga *et al*. (1985) in Florida (USA), Dhaliwal *et al*. (1996) in England, and Grosshans *et al*. (1997) in New Zealand, respectively. Differences in environmental conditions and management were probably the causes of the large differences reported.

It is interesting to note that the herd, studied in the present experiment, was managed under optimal conditions, in which cows were shaded, cooled by the use of fans and sprinklers, and fed a balanced, total ration throughout the year. However, these conditions were not sufficient to improve fertility of the herd. The effectiveness of environmental modifications to increase conception rates of dairy cattle was shown by several studies (Roman-Ponce *et al*., 1977; Ryan *et al*., 1992). For example, the simple provision of shade to cows during the summer reduced number of IPC from 4.0 to 2.3 (Roman-Ponce *et al*., 1977). According to Hansen *et al*. (1992), the amount of cooling to which cows are routinely exposed and the proper design of housing systems are not often sufficient to allow acceptable pregnancy rates. The reason for this is the inability of cooling procedures in addition to inadequate thermoregulation in the animals, especially the morphological hair coat characteristics. Not surprisingly though, the complete elimination of heat stress by cooling systems is a major challenge in a hot, humid tropical environment, especially in high-yielding, purebred Holstein cows.

Low but significant correlations between coat characteristics and the number of IPC indicated that cows, with thicker, denser coats with thin hairs and large proportions of black area, had a higher number of IPC. This was likely due to the fact that hair coat characteristics are important factors in the thermoregulatory processes in hot and humid environments. However, the correlation coefficients were small and might not be of practical importance.

According to previously studies, it has been suggested that a low hair coat score (sleek coat) was associated with a high growth rate in calves, high fertility in breeding cows, and high birth weight in calves (Turner and Schleger, 1958). These results can be justified by the importance of the coat for the heat dissipation (Turnpenny *et al*., 2000). The morphological and physical hair coat characteristics affect the energy transfer from the skin to the environment and consequently, body temperature control (Cena and Monteith, 1975a; b; Finch *et al*., 1984; Hutchinson and Brown, 1969; Kovarik, 1973; Silva *et al*., 1988; McArthur, 1991; Silva, 1999).

Another important aspect was the age of the animal; its variance as well as the effect of parity was probably a consequence of the physiological differences among heifers and primiparous and multiparous cows. These results might be partially explained by the higher incidence of diseases during the early postpartum period, which affect the reproductive performance of lactating dairy cows in comparison to heifers (Gröhn and Rajala-Schultz, 2000). On the other hand, Sartori *et al*. (2002) showed that lactating cows were more susceptible to heat stress than non-lactating cows, probably because lactating cows have a higher body temperature than heifers exposed to the same environment. These authors reported fertilization rates of 50 % for lactating cows and 100 % for heifers in the summer season; however, there were no differences in fertilization rate between heifers and lactating cows during the winter. Variation in the number of IPC throughout the years suggests that part of the differences were probably generated by environmental and management conditions in each year.

With respect to the coat type, hair thickness affects variation in the number of IPC the most. The lowest number of IPC was observed in cows with a thin coat layer. It must be emphasized that the cows used in the present study had a thin hair thickness (2.48 mm), a value lower than the values cited for cows in other tropical environments. Therefore, there seems to be a limitation on adaptation of breed for a given environment, as suggested by Finch (1984) and Burrow (2001).

The low number of IPC reported for cows with a thin coat layer could be due to the better thermal balance that occurs with this type of coat. This explanation agrees with the theoretical physical principles of heat transfer associated with hair coats (Cena and Monteith, 1975a; b; Gebremedhin *et al*., 1997; Turnpenny *et al*., 2000); coats with thick, short, packed, well-settled hairs produce a high latent and sensible heat flux from the skin to the coat surface. Thus, the greater resistance of a thick coat contributes to an increased thermal stress and subsequently, decreased fertility. Bonsma (1949) was probably the first to relate coat characteristics to cattle productivity and fertility.

The reduction in embryonic survival around the time of insemination is due to the sensitivity of the oocyte or embryo to an elevated temperature in the oviduct. The heat resistance decreases from the oocyte to the two-cell embryo (Edwards and Hansen, 1997). Putney *et al*. (1989) showed that superovulated heifers, exposed to heat stress 10 hours before insemination, had increased numbers of degenerate embryos and non-fecundated oocytes. On the other hand, Ryan *et al*. (1993) reported that embryo viability in superovulated cows, collected on the Day 6 or 7 post insemination, did not significantly differ between the hot and cool seasons; however, embryo viability decreased significantly (P < 0.05) from 59% on Day 7 to 27% by Days 13 or 14 in the hot season, but not during the cool season. Pregnancy rate at 25 to 35 days was 21% during the hot season, which was significantly less (P < 0.05) than the observed 36 % in the cool season.

As for the coat color, the number of IPC decreased with the increase in the percentage of black hairs, but the least squares means did not differ (P > 0.05). An earlier study by King *et al.* (1988) in Arizona on the effects of coat color on reproductive performance of Holstein cows managed under shade with sprinklers reported a significant interaction between coat color and days open. Cows had fewer days open during February and March and the number of IPC was lower in totally white cows. Similar results from King *et al.* (1988) were observed by Becerril *et al.* (1993) who reported negative regression coefficients for reproductive traits in association with dark coat color, but their values were not statistically significant.

Hansen (1990) found interactions between color and environment (shaded and unshaded areas) for physiological variables for Holsteins grouped by percentage of white hair. Cows with white hair, exposed to sun without shade, had smaller changes in the physiological variables and less depression in milk yield. In agreement, Maia *et al.* (2005) reported that milk yield in predominantly (> 70%) white-haired cows tended to be higher than in predominantly black cows, using cows of the same herd as the present study.

The lower number of IPC of cows with more than 70% black hairs in the present study was not expected because predominantly black cows have a greater absorption of thermal radiation. This leads to increased coat surface and rectal temperatures (Hansen, 1990; Gebremedhin *et al*., 1997; Silva, 2000b), thus reducing the ability of the animal to dissipate heat. In addition, increased thermal stress decreases conception rate (King *et al*., 1988; Becerril *et al*., 1993). Our results may have been due to the fact that the cows were managed under shade structures, protected against the direct solar radiation, and provided with fans and sprinklers. On the other hand, it is important to note the direct and indirect potential effects of solar radiation on animal physiology or performance in a tropical environment, regardless of coat color (Walsberg 1983; Gebremedhin *et al*., 1997; Silva, 1999). A black coat exchanges more or less heat depending on the characteristics of the organism including the physical structure of the coat and the atmospheric conditions. However, it is important to maintain cows with large proportion of black hairs under shade because in the Holsteins, a black coat covers a highly pigmented skin. In fact, a high pigmented skin is better protected against short-wave radiation and consequently, sunburn lesions and tumors according to Silva (1999). Silva *et al.* (2001) suggested that the best choice for tropical environments would be a white coat with a low radiation transmittance over a black skin. However, the authors concluded that this is a combination hardly found in Holstein cattle, and an alternative choice would be a black coat with high transmittance.

In a previous study, Maia *et al*. (2003) showed significant differences between black and white hair coats in Holsteins, reporting that white hair coats were denser with hairs longer than those of the black coats. In a further study, Maia *et al* (2005) verified that the effective transmissivity of the black coat was very similar to that of the white one, considering coats of similar morphological characteristics. On the other hand, the effective absorptive ability was greater for dense coats with short hairs than for those with less-dense hair, being greater in black than in the white coats. These results are in agreement to the present observations of best IPC performance in cows with larger proportion of black hairs. However, black coats were less dense, with thicker and shorter hairs according to Maia *et al.* (2003), and those characteristics improve heat tolerance in tropical environments in spite of the black color of hairs and skin (which give a better protection against ultra-violet radiation).

In conclusion, Holstein cows with thin hair coats (less than 2 mm), which can be considered as the most fit to tropical environments, had a fewer number of IPC than those with thick coats (>3 mm).

The present study was conducted in an intensive commercial dairy herd under tropical conditions, under shade, and provided with cooling systems (fans and sprinklers) and showed a picture of the effect of coat characteristics on the reproductive performance of cows. This experiment has provided basic data for further investigations on the effect of the heat stress on infertility. It suggests also the importance of the genetic improvement of Holstein cows for hair coat characteristics and potentially for other animals bred in tropical environments.

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