MASTER INTERUNIVERSITARIO EN MEJORA GENÉTICA ANIMAL Y BIOTECNOLOGÍA DE LA REPRODUCCIÓN

Genética de la respuesta al estrés térmico en una raza autóctona de ganado caprino lechero

Genetic response of heat stress on performance of Spanish local dairy goat breed

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Abstract

In the present thesis the effect of heat stress on milk, fat, and protein yields and fat and protein contents has been studied in the Spanish Florida breed of dairy goats. It comprises three chapters: The first one is a bibliographic review of the state of the art. The second one is a phenotypic analysis carried out to determine the climatic variables most correlated to the production traits and to estimate the tolerance thresholds and slopes of the responses of the dairy traits studied to heat stress. The third chapter is a genetic analysis of formerly cited responses, undertaken with the objective to estimate the environmental and genetic (co)variance components of heat stress tolerance. A total of 185,675 test-day records belonging to 13,481 lactating goats distributed in 20 flocks, collected between 2006 and 2012, combined with maximum and average temperatures and the values of an index of temperature and relative humidity (THI), registered the day of milk recording and one and two days before in meteorological stations located less than 22 Km from the farms, were used for the phenotypic and genetic analysis. For the first study, a Ridge regression analysis and a GLM select analysis were carried out in order to select the climatic variables and dates that were recorded, having the highest correlations with the dairy traits under study. Then, tolerance thresholds and slopes of the regressions of these traits with the selected climatic variables were estimated with spline and polynomial models by means of Bayesian methods. Results shows that the maximum and average temperatures (mean of maximum and minimum temperatures) explain the change in dairy traits caused by climatic effects better than the THI. Temperatures registered the day of milk recording or one day before have more effect on the traits studied than those registered two days before. Generally, yields and contents of milk components decrease when temperature increases. However, milk yield seem to be less affected by high temperatures, being more affected by cold temperatures. Climatic variables have a higher effect on milk composition in high productive animals in respect to the rest. For the genetic analysis, a reaction norm animal model (RNM) was used to estimate the genetic and permanent environmental (co)variance components of the relation of dairy traits with THI, maximum and average temperature, modeling this relation by means of Legendre polynomials. Results show that the heritability of dairy traits tends to decrease for increasing values of the climatic variables. Genetic correlations between the intercept and the slope of each model, and between the first and the subsequent points in the scales of the climatic variables, provide evidences that selection for better milk performance will reduce heat stress tolerance. The genetic variation of the response to heat stress found in this analyses could be used to select animals according to their response to heat stress (robust, tolerant and non-tolerant).

Key words: Florida goats, heat stress, climatic variables, genetic parameters.

Resumen

La presente tesis trata del efecto del estrés térmico sobre las producciones de leche, grasa y proteína y sobre los contenidos de estas dos últimas componentes de la leche de las cabras de la raza autóctona española Florida. La tesis está organizada en tres capítulos: En el primero de ellos se realizó una revisión bibliográfica del tema. En el segundo se describe un análisis realizado para determinar, a nivel fenotípico, las variables climáticas más correlacionadas con los caracteres productivos y estimar el umbral y la pendiente de la tolerancia de la respuesta al estrés térmico de dichos caracteres. El tercer capítulo trata de un análisis genético realizado con el objetivo de estimar los componentes de (co)varianza genéticos y ambientales de la tolerancia al estrés térmico. Para llevar a cabo los análisis fenotípico y genético 185675 registros del día de control de la producción y composición de la leche de, tomados de 13481 cabras distribuidas en 20 rebaños, se combinaron con los datos de temperatura máxima y media y un índice de temperatura y humedad relativa (THI), registrados el mismo día del control lechero, dos y un día antes, en estaciones meteorológicas ubicadas a menos de 22 Km de cada explotación. En este primer estudio, se utilizaron los métodos de regresión “Ridge” y “GLM select” para seleccionar las variables climáticas, y las fechas de registro de las mismas, mas correlacionadas con los registros de los caracteres lecheros en estudio. A continuación, se estimaron el umbral y la pendiente de la respuesta de los caracteres lecheros a cada una de las variables climáticas seleccionadas anteriormente, mediante modelos lineales y polinómicos, utilizando para ello métodos Bayesianos. Los resultados muestran que las temperaturas máxima y media (promedio de las temperaturas máxima y mínima) explican el cambio en las características lecheras causados por los efectos climáticos mejor que el THI. Las temperaturas registradas el día de control o un día antes tienen más efecto sobre los caracteres estudiados que la registrada dos días antes. En general, las producciones y los contenidos de los componentes de la leche estudiados disminuyen cuando aumenta la temperatura. Sin embargo, la producción de leche parece ser menos sensible a las altas temperaturas y más sensible al frio. Las variables climáticas tienen un efecto mayor sobre la composición de la leche de los animales de alto nivel productivo que sobre el resto. En el genético estudio, se utilizó un modelo de norma de reacción (RNM) para estimar los componentes de (co)varianza genéticos y ambientales permanente de las relaciones entre los caracteres lecheros y cada una de las variables climáticas (THI y temperaturas máxima y media), incorporadas en los modelos de análisis mediante polinomios de Legendre. Los resultados obtenidos reflejan que las heredabilidades de las características lecheras muestran una tendencia negativa cuando los valores de las variables climáticas aumentan. Las correlaciones genéticas entre la intersección y la pendiente de cada uno de los modelos, y entre el primero y los puntos posteriores en las escalas de valores de las variables climáticas, proporcionan una evidencia de que selección para lograr un mejor rendimiento lechero disminuye la tolerancia al estrés térmico. La variación genética de la respuesta al estrés térmico observada en estos análisis podría ser utilizada para seleccionar los animales en función de dichas repuestas (robustas, tolerantes y no tolerantes).

Palabras clave: Cabras de la raza Florida, estrés térmico, variables climáticas, parámetros genéticos.

CHAPTER 1

Literature review

1. 1. Selection for milk production

Artificial selection has resulted in highly productive domestic animals. Dairy animal research has tended to concentrate on genetic improvements to increase milk yield. As a result, average world daily milk yield per animal has increased during the last decade for cattle, goats and sheep from 22,145 to 23,275 g, 831 to 882 g and 422 to 482 g, respectively (FAO, 2013). In fact, such an increase in milk yield is mostly due to the environmental and genetic improvements carried out in the more developed countries, like Spain, where dailly milk yield per animal has increased in the same decade, from 53.520 to 74.966 Kg in cattle, from 3.340 to 4.463 Kg in goats and from 1.169 to 1.829 Kg in sheep (Table 1.1, modified from FAO Statistics Division 2013). According to FAO statistic, Spain was the sixth and fifteenth country in the world with respect to goats milk production and milk yield per animal, respectively, in 2011 (FAO, 2013).

Table 1. 1. Animal stocks (heads), yearly milk production (tonnes) and daily milk yield per animal (g) in the world and in Spain.

Country	Item	Element	2000		2005		2010	
World (Total)	Cattle	Stocks	1,313,205,036	A	1,368,026,229	A	1,430,101,597	A
		Milk prod.	490,143,010	A	544,446,616	A	600,838,992	A
		Milk yield	22,145	Fc	22,423	Fc	23,275	Fc
	Goats	Stocks	751,404,512	A	838,623,162	A	909,691,096	A
		Milk prod.	12,701,671	A	14,876,838	A	17,374,310	A
		Milk yield	831	Fc	851	Fc	882	Fc
	Sheep	Stocks	1,059,736,756	A	1,099,671,843	A	1,077,762,456	A
		Milk prod.	8,103,580	A	8,951,352	A	10,091,309	A
		Milk yield	422	Fc	457	Fc	482	Fc
Spain	Cattle	Stocks	6,216,880		6,463,430		6,075,100	
		Milk prod.	6,106,630		6,370,200		6,357,140	
		Milk yield	53,520	Fc	62,947	Fc	74,966	Fc
	Goats	Stocks	2,627,000		2,904,690		2,933,800	
		Milk prod.	438,541		471,900		602,000	*
		Milk yield	3,340	Fc	3,742	Fc	4,463	Fc
	Sheep	Stocks	23,965,000		22,749,500		18,551,600	
		Milk prod.	392,043		407,800		585,190	
		Milk yield	1,169	Fc	1,801	Fc	1,829	Fc

Source: FAO Statistics Division (2013), A = Aggregate (may include official, semi-official or estimated data), Fc = Calculated data, * = Unofficial figure.

By maintaining animals under exposure to natural selection, FAO's Committee on Genetic Resources for Food and Agriculture (CGRFA, 2009) noted that pastoralists and small-scale livestock keepers play a crucial and essential role in the sustainable use of adaptation and fitness traits. On the other hand, artificial selection breeds are selected mostly for production characteristics and they are not exposed to such a strong natural environmental stressors. As a result genetic improvement has caused undesirable side effects such as low reproductive efficiency, increased susceptibility to diseases and higher sensitivity to sudden environmental changes (Rauw *et al.*, 1998). In particular, improvements carried out to increase milk yield have tended to concentrate on artificial selection and on nutrients supply, as it is known that milk production is positively correlated to feed intake. However, increases of both milk production and feed intake are positively correlated to metabolic heat production (Kadzere *et al.*, 2002). As production levels of the animal increase, metabolic heat output also increases. It has been demonstrated that general productivity and heat tolerance are antagonistic (Johnson *et al.*, 1962), this leads to reduced heat tolerance and, consequently, to lower production in hot climates. When dairy animals are exposed to heat stress for extended periods of time, the ability of the lactating dairy animal to disperse heat decreases. So, the large quantity of metabolic heat produced by the dairy animal joined to their decreased cooling capability, caused heat stress (Gantner *et al.*, 2006). In summary, artificial selection to increase milk yield has been demonstrated to reduce heat tolerance in dairy cattle (Ravagnolo and Misztal, 2000; Bohmanova *et al.*, 2007), dairy sheep (Finocchiaro *et al.*, 2005) and dairy goats (Menéndez-Buxadera *et al.*, 2012a).

1. 2. Adaptation and acclimation

Adaptability of an animal can be defined as the ability to survive and reproduce within a defined environment (Prayaga and Henshall, 2005), or the degree to which an organism, population or species can remain/become adapted to a wide range of environments by physiological or genetic means (Barker, 2009). Finch (1984) defined adaptation to the thermal environment as the internal readjustment to maintain homeostasis in the face of external temperature changes. Adaptation to harsh environmental factors, which may be due to hot and dry, hot and humid weather, high altitude and cold weather or large seasonal and annual variations of climatic conditions, is largely based on genetics (Mirkena *et al.*, 2010). There is ample evidence that livestock breeds and population that have evolved over the centuries in diverse, stressful harsh environments have a range of unique adaptive traits which enable them to survive and be productive in such environments (Baker and Gray, 2004). Therefore, there are differences among species and breeds in respect to their sensitivity to ambient temperature and level of moisture in the air. For example, sheep and goats have been observed to be more heat tolerant than cattle (Oseni and Bebe, 2010; Sevi and Caroprese, 2012). Within the same species, there are differences between breeds. Muller and Botha (1993) stated that Jersey cows display a higher heat tolerance than Friesian cows, and that Jerseys should be more widely used in warmer regions. Similarly in sheep breeds, Srikandakumar *et al.* (2003) reported that Omani sheep is more heat tolerant than Merino sheep.

Other aspect that should be considered is individual acclimation. It is a phenotypic response developed by the animal to a specific source of stress in the environment (Fregley, 1996). The acclimation of the animals to meet the thermal challenges results in the reduction of feed intake, alteration of many physiological functions and of productive and reproductive efficiency (Lacetera *et al.*, 2003). The thermal environment is a major factor that can negatively affect milk production and it is considered one of the main causes of economic losses in animal production (St-Pierre *et al.*, 2003). An impairment of production and reproduction performances has been observed when animals are exposed to heat stress, as a result of the impairment of biological functions, including depression in feed intake and utilization, disturbances in the metabolism of water, protein, energy and mineral balances, enzymatic reactions, hormonal secretions and blood metabolites (Marai *et al.*, 2007).

However, little attention has been paid to the less thermoregulatory ability of the selected dairy animals as a consequence of the increase in their capacity to produce milk. Such an undesirable effect could be observed in dairy cattle when an increase of milk production from 35 to 45 kg/day caused the threshold temperature for heat stress to be reduced by 5°C (Berman, 2005).

1. 3. Estimating the severity of heat stress

Stress was defined by Lee (1965) as an external event or condition that produces a “strain” in a biological system. Similar definition was mentioned by Yousef (1985), who defined stress as the magnitude of forces external to the body which tend to displace the systems from their resting or ground state. Armstrong (1994) stated that heat stress occurs when any combination of environmental conditions cause the effective temperature of the environment to be higher than the animal’s thermo neutral (comfort) zone.

Bohmanova *et al.* (2007) referred that the term heat stress implies the state of a body exposed to long term adverse effects of one or more climate factors where, the more productive the animal the more pronounced is the stress. Marai and Haeeb (2010) defined heat stress as the state at which some mechanisms are activated to maintain an animal's body thermal balance when exposed to intolerable (uncomfortable) elevated temperature. Thus, heat stress results from a negative balance between the net amount of energy flowing from the animal to its surrounding environment and the amount of heat energy produced by the animal (Farooq *et al.*, 2010). It is caused by a combination of environmental factors (temperature, relative humidity, solar radiation, air movement, and precipitation). According to Marai *et al*. (2007) and Marai and Haeeb (2010) the environmental factors associated with heat stress, which affect the physiological systems governing thermal regulation and the maintenance of positive heat loss, are primarily ambient temperature, relative humidity (RH%) and radiant energy. Therefore, evaluation of air temperature alone does not permit an accurate assessment of the effects of the thermal environment on physiology, welfare, health, and productivity of farm animals (Segnalini *et al.*, 2011).

Over the last decades, many indices combining different environmental factors have been proposed to measure the level of heat stress. However, the lack of data, publicly available, on the amount of thermal radiation received by the animal, the wind speed, precipitation and rainfall limited their use. Therefore, the majority of studies on heat stress in livestock have focused mainly on temperature and amount of moisture in the air, which can be easily obtained on a daily basis from a meteorological station located nearby the farm. Besides, water vapor content of the air, or relative humidity, has an impact on the rate of evaporative loss through the skin and the lungs. West (2003) stated that high humidity in combination with high temperatures reduces the potential for evaporative heat loss. So, it is considered a significant element to maintaining the homeostasis of the animal when the mean daily temperature falls outside of the animal’s comfort zone. The severity of heat stress is correlated to both ambient temperature and humidity level and the effect of heat stress is aggravated when high temperature is accompanied with high ambient humidity (Marai *et al.*, 2007).

In practical terms, there was a need to develop a simple, trusted and easy to determine parameter to accurately assess the potential of the climatic variables to induce heat stress. As a result, a measurement of temperature-humidity index (THI) was developed to indicate the degree of stress and to determine its influence on dairy animal as a measure of the combined effect of temperature and humidity, which are the climate variables most closely involved in heat balance. (Bianca, 1962; NRC, 1971). As a measure of the level of heat stress, THI began to be used in the mid 20th century when it was originally developed by Thom (1958) as an index to measure the levels of discomfort of humans during summer months. Its use was extended to bovines by Johnson *et al.* (1961). Afterwards, the THI has become a standard tool for many studies and applications in animal biometeorology (Hahn *et al.*, 2003).

A number of calculation methods have been developed over the years to establish THI (Table 1.2). Depending on the author, formulas are based on different weightings of dry bulb temperature (T_{db}) and air moisture. THI integrate air moisture in the index by means of the relative humidity (RH), which provides information about water saturation of the air at a given temperature (Kelly and Bond, 1971; NOAA, 1976; LPHSI, 1990; Finocchiaro *et al.*, 2005; Mader *et al.*, 2006). Others use wet bulb temperature (T_{wb}), which represents the equilibrium temperature of a thermometer covered with a cloth that has been wetted with pure water (Thom, 1959; Bianca, 1962; NRC, 1971) or dew point temperature (T_{dp}), the temperature to which the air must be cooled for saturation to occur; that is, the temperature at which RH is 100% (NRC, 1971; Yousef, 1985).

Table 1. 2. Formulas to calculate Temperature Humidity Index (THI).

Formula	Reference
$THI1= T_{db}\,°F-[(0.55-0.55*RH)*(T_{db}\,°F-58)]$	Kelly and Bond (1971); NOAA (1976) and LPHSI (1990)
$THI2= (0.8*T_{db}°C)+((RH)*(T_{db}\,°C-14.4))+46.4$	Mader *et al.* (2006)
$THI3= T_{db}\,°C -[0.55 * (1 -RH)] * (T_{db}\,°C -14.4)$	Finocchiaro *et al.* (2005)
$THI4= T_{db}\,°C -[(0.31 - 0.31\,RH)(T_{db}\,°C - 14.4)]$	Marai *et al.* (2007)
$THI5= T_{db}\,°C+(0.36*T_{dp}°C)+41.2$	Yousef (1985); Bosen (1959) and Kibler (1964)
$THI6= (0.55*T_{db}\,°C +0.2*T_{dp}°C)*1.8+32+17.5$	NRC (1971)
$THI7= (0.35 \times T_{db}\,°C + 0.65 \times T_{wb}°C) \times 1.8 + 32$	Bianca (1962)
$THI8= (0.15 \times T_{db}\,°C + 0.85 \times T_{wb}°C) \times 1.8 + 32$	Bianca (1962)
$THI9= [0.4 \times (T_{db}\,°C + T_{wb}°C)] \times 1.8 + 32 + 15$	Thom (1959)
$THI10= (T_{db}\,°C + T_{wb}°C) \times 0.72 + 40.6$	NRC (1971)

T_{db}: dry bulb temperature; T_{wb}: wet bulb temperature; T_{dp}: dew point temperature; RH: relative humidity.

The typical definition of heat tolerance is the ability of the animals to maintain expression of their inherited functional potential during their life-time when raised under hot conditions (Marai and Haeeb, 2010). Numerous studies have been performed to establish comfortable zone and heat tolerance thresholds in dairy animals on the basis of THI values. Milk production in dairy cows is affected by heat stress when mean THI values are lower than 35 and higher than 72 (Johnson, 1980 and 1987; Du Preez *et al.*, 1990a; Ravagnolo *et al.*, 2000). THI values from 72 to 79 indicate an external temperature stressogenic for the cow's body. When THI is above 79, the external temperature has a very stressogenic effect on health of the animal, especially in the case of lactating cows, who are not able to activate mechanisms of thermoregulation to maintain their body temperature within physiological limits under such physiological conditions (West, 2003).

Du Preez *et al.* (1990a) demonstrated that milk production is affected by heat stress when THI values are higher than 72, which corresponds to 22 °C at 100 % humidity, 25 °C at 50 % humidity, or 28 °C at 20 % humidity. Wiersma (1990) developed a graph of heat stress indices (Figure 1.1) to be used by dairy producers to estimate the severity of heat stress on dairy cows. This chart utilizes ambient temperature and relative humidity, which can be easily obtained on a daily basis and it indicates the ranges from mild to severe heat stress on dairy cattle. These values of THI and estimates of the heat stress were calculated according to a specific formula (given in the title of Figure 1.1) and could be different using another formula.

Sheep and goats are thought to be more resistant species than cattle to extreme climatic conditions, especially to high ambient temperatures (Sevi and Caroprese, 2012). Oseni and Bebe (2010) reported that sheep and goats show higher adaptability ranking to heat stress than cattle. Moreover, Silanikove (1997) stated that goats are the best adapted to harsh hot environments among the domestic ruminant species. In addition, breeds of ruminants indigenous to tropical and subtropical environments generally performed better under heat stressful conditions than their counterparts from more temperate zones in terms of survival, reproduction and expression of their genetic potential for growth and milk yield (Finch, 1984).

DEG F	DEG C	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
72	22.2																				72	72
73	22.8																		72	72	73	73
74	23.3																72	72	73	73	74	74
75	23.9														72	72	73	73	74	74	75	75
76	24.4												72	72	73	73	74	74	75	75	76	76
77	25.0											72	72	73	73	74	74	75	75	76	76	77
78	25.6										72	73	73	74	74	75	75	76	76	77	77	77
79	26.1									72	73	73	74	74	75	76	76	77	77	78	78	79
80	26.7							72	72	73	73	74	74	75	76	76	77	78	78	79	79	80
81	27.2						72	72	73	73	74	74	75	76	77	77	78	78	79	80	80	81
82	27.8						72	73	73	74	75	75	76	77	77	78	79	79	80	81	81	82
83	28.3					72	73	73	74	74	75	76	77	78	78	79	80	80	81	82	82	83
84	28.9				72	73	73	74	75	75	76	77	78	78	79	80	80	81	82	83	83	84
85	29.4			72	72	73	74	75	75	76	77	78	78	79	80	81	81	82	83	84	84	85
86	30.0			72	73	74	74	75	76	77	78	78	79	80	81	81	82	83	84	84	85	86
87	30.6		72	73	73	74	75	76	77	77	78	79	80	81	81	82	83	86	85	85	86	87
88	31.1	72	72	73	74	75	75	76	77	78	79	80	81	81	82	83	84	85	86	86	87	88
89	31.7	72	73	74	75	76	76	77	78	79	80	80	81	82	83	84	85	86	86	87	88	89
90	32.2	72	73	74	75	76	77	78	79	79	80	81	82	83	84	85	86	86	87	88	89	90
91	32.8	73	74	75	76	76	77	78	79	80	81	82	83	84	85	86	86	87	88	89	90	91
92	33.3	73	74	75	76	77	78	79	80	81	82	83	84	85	85	86	87	88	89	90	91	92
93	33.9	74	75	76	77	78	79	80	80	81	82	83	84	85	86	87	88	89	90	91	92	93
94	34.4	74	75	76	77	78	79	80	81	83	83	84	85	86	87	88	89	90	91	92	93	94
95	35.0	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
96	35.6	75	76	77	78	79	80	81	82	83	85	86	87	88	89	90	91	92	93	94	95	96
97	36.1	76	77	78	79	80	81	82	83	84	85	86	87	88	89	91	92	93	94	95	96	97
98	36.7	76	77	78	79	80	82	83	84	85	86	87	88	89	90	91	93	94	95	96	97	98
99	37.2	76	78	79	80	81	82	83	84	85	87	88	89	90	91	92	93	94	96	97	98	99
100	37.3	77	78	79	80	82	83	84	85	86	87	89	90	91	92	93	94	95	97	98	99	
101	38.3	77	79	80	81	82	83	86	86	87	88	89	90	92	93	95	95	96	97	99		
102	38.9	78	79	80	81	83	86	85	86	87	89	90	91	92	93	95	96	97	96			
103	39.6	78	79	81	82	83	86	86	87	88	89	91	92	94	95	96	97					
104	40.0	79	80	81	82	86	85	86	88	89	90	91	93	95	95	96						
105	40.6	79	80	82	83	86	86	87	88	89	91	92	93	95	96	97						
106	41.1	80	81	82	86	85	86	88	89	90	91	93	94	95	97	98						
107	41.7	80	81	83	86	85	87	88	89	91	92	94	95	96	98							
108	42.2	81	82	83	85	86	87	89	90	92	93	94	96	97								
109	42.3	81	82	86	85	87	88	89	91	92	94	95	96	98								
110	43.3	81	83	86	86	87	88	90	91	93	94	96	97									
111	43.9	82	83	85	86	88	89	91	93	94	95	96	98									
112	44.4	82	86	85	87	88	90	91	94	94	96	97										
113	45.0	83	86	86	87	89	90	92	95	95	96	96										
114	45.4	83	85	86	88	89	91	92	94	96	97											
115	46.1	86	85	87	88	90	91	94	95	96	98											
116	46.7	86	86	87	89	90	92	94	95	97												
117	47.2	85	86	88	89	91	93	94	96	98												
118	47.3	85	87	88	90	92	93	95	97													
119	48.3	85	87	89	90	92	94	96	97													
120	48.9	86	88	89	91	93	94	96	98													
121	49.4	86	88	90	92	93	95	97														

< 72 F = No Stress

72-78 = Mild Stress

78-89 = Moderate Stress

89-98 = Very Severe Stress

>98 = Dead Cows

Figure 1. 1. Chart showing the regions and ranges of values of a temperature and humidity index (THI) and their severity of heat stress on dairy cows: THI= (Dry-Bulb Temp. °C) + (0.36 * dew point Temp. °C) + 41.2 (Wiersma, 1990).

Thermo neutral zones and tolerance thresholds in sheep widely vary between breeds. Curtis (1983) estimated the thermo neutral zone in sheep to be between 5 °C and 25 °C. Finocchiaro *et al.* (2005) observed that heat stress affects Mediterranean dairy sheep production when THI ≥ 23. This is a lower value than that reported by Sevi *et al.* (2001) for the related Comisana dairy sheep breed, in which animals suffered from heat stress only when THI ≥ 27.

Taylor (1992) reported a comfort zone for an adult sheep with full fleece between -12 and 32 °C. This is in agreement with Srikandakumar *et al.* (2003) results for heat stress in Omani and Australian Merino sheep breeds reared in Oman. In that study, animals showed effects of heat stress when THI was ≥ 32. Sevi *et al.* (2001) also mentioned that heat stress was induced in lactating ewes as a result of prolonged exposure to maximum air temperature over 30 °C and to THI higher than 80. The Livestock and Poultry Heat Stress Indices, Agricultural Engineering Technology Guide (LPHSI, 1990) established the following categories of temperatures measured in °F: values<82 = absence of heat stress; 82 to <84 = moderate heat stress; 84 to <86 = severe heat stress and over 86 = extreme severe heat stress. When temperature is expressed in °C, the categories are the following: <22.2 = absence of heat stress; 22.2 to <23.3 = moderate heat stress: 23.3 to <25.6 = severe heat stress and 25.6 and more = extreme severe heat stress (Marai *et al*., 2001).

1. 4. Effect of heat stress on milk production

It is well established that milk production is not affected by low and moderate temperatures, while after passing a threshold value milk production starts to decrease and then the rate of decline increases with rising temperatures (Armstrong, 1994). According to Du Preez *et al.* (1990a), milk production is not affected by heat stress when mean THI values are between 35 and 72.

For lactating dairy cows, the ambient temperatures above 25 °C are associated with lower feed intake, drops in milk production and reduced metabolic rate, as reported by Berman (1968). Critical maximum temperature for cows is assumed to be at the level of 25-26°C (West, 2003) or 24-27°C (Brouček *et al.*, 2009). When the temperature exceeds 27°C even with low humidity the effective temperature is above the comfort zone for high producing dairy cows (Armstrong, 1994). Johnson *et al.* (1962) showed a linear reduction of dry matter intake and milk yield when THI exceeded 70. Reduction of milk yield was

0.26 kg/day per unit of THI. Johnson (1980) stated that milk production and feed intake begin to decline when THI reaches 72 and it continues declining sharply at THI values over 76. Milk yield decreases of 10 to 40% from winter to summer have been reported for Holstein cows (Du Preez *et al.*, 1990b). At 29 °C and 40 % relative humidity, Bianca (1965) determined decreases of daily milk yield of 3, 7 and 2 % in Holstein, Jersey and Brown Swiss cows, respectively. Additional decreases of milk yield of 31, 25, and 17 % were observed in former breeds when relative humidity increased up to 90 %.

Ravagnolo *et al.* (2000) stated that milk yield appears relatively constant until about 24°C and then declines at a pace of 0.2 kg per unit increased in THI when THI exceeded 72. Gantner *et al.* (2011) reported that the bovine thermal comfort zone is -13 °C to +25 °C. Within this temperature range, the animal comfort is optimal, with a body temperature ranging between 38.4 °C and 39.1°C. Above 25 °C, the cow suffers from heat stress and its health status and production performances are affected. Under Mediterranean climatic conditions, Bouraoui *et al.* (2002) reported drops in milk yield of 0.41 kg per cow and day for each point of increase in the value of THI above 69. The same authors estimated a negative correlation (r = -0.76) between milk yield and THI. Besides, they referred that as the THI values increased from 68 to 78, milk production decreased 4 kg. Gentner *et al.* (2006) indicated that milk production decreased as THI increase and the most intensive decrease took place between 60 and 120 days of lactation. A highly significant decrease of daily milk yield due to high THI values was also observed in heifers and cows by Gantner *et al.* (2011).

Similarly, Samolovac *et al.* (2012) studied the effect of climate factors on daily milk yield of Holstein-Frisian cows in seven farms of the PKB Corporation and they found that milk yield was the lowest, amounting to approximately 21.5 kg, when external air temperatures, as well as THI values, were the highest (July and August) , while in periods with relatively low temperatures and THI (from late autumn until the spring) daily milk yields were the highest, in the interval between 22.5 and 24.3kg.

Other researches have investigated the effect on milk yield of measures of climatic variables registered different days earlier than milk test day. West *et al.* (2003) mentioned that during hot weather, the mean THI registered two days earlier than test day had the greatest effect on milk yield. Milk yield of Holsteins declined 0.88 kg per each unit of the THI registered two days before the day of milk recording. The authors presumed that the delayed impact of climatic variables on production could be related to an altered feed intake and a delay between the intake and the utilization of nutrients and corresponding changes in the endocrine status of the cow. Herbut and Angrecka (2012) recorded a decrease in milk production 4 days after starting to register high temperatures. Production decrease varied from 0.18 to 0.36 kg per THI unit depending on the level of milk production of the cow.

Milk yield losses seem positively correlated with the production level of the cow (Berry *et al.*, 1964). Coppock *et al.* (1982) concluded that high-producing cows are more affected by heat stress than low-producing cows, because the zone of thermal neutrality shifts to lower temperatures as milk production, feed intake, and metabolic heat production increase. An increase of milk yield increases the sensitivity of cattle to thermal stress and reduces the "threshold temperature" at which milk losses occur (Berman, 2005). For example Purwanto *et al.* (1990) stated that the heat produced by cows yielding 18.5 and 31.6 kg/day of milk was 27.3 and 48.5% higher, respectively, than that of non-lactating cows. Similarly, Johnson *et al.* (1988) found a higher average decline of persistency in cows yielding more than 30 kg/day (-0.059 % per day) compared with cows yielding less than 25 kg/day (-0.019 % per day). This is because metabolic heat production increases as the production level of the cow increases (Kadzere *et al.*, 2002).

In a recent re-evaluation of the impact of the temperature humidity index on milk production in high milk yielding dairy cows, Collier *et al.* (2011) observed a linear decrease in milk yield for THI values between 60 and 80, which indicates that milk yield losses occurred well below a THI threshold of 72. They also reported that a daily THI equal to 68 results in a loss of 2.2 kg/day. The lower THI at which heat stress occurs and milk production began to descend could be due to the increase in the average production per cow (over 30 kg/day, with many cows producing above 50 kg/day at lactation peak) and the consequent reduction of heat tolerance. Similarly, Berman (2005) reported a drop of 5°C in the threshold temperature for heat stress when milk production increased from 35 to 45 kg/day.

Few researches on THI as an indicator of heat stress and its effects on milk production in sheep and goats have been carried out. Sevi *et al.* (2001) reported a reduction of milk yield after ewe exposure to temperatures over 35 ºC, even for short periods of time. However, Menéndez-Buxadera *et al.* (2012b) reported a decline in sheep milk production at THI=45 and that decline reached 98 g/day every increase of 5 degrees in THI. Menéndez-Buxadera *et al.* (2012a) observed genetic variation for heat stress tolerance in Murciano-Granadina and Payoya goats which, according to these authors, could be used for selection purposes. The patterns of genetic correlation between the values of milk traits registered at different THI levels showed the reduction in heat stress tolerance to be a correlated response to selection for higher milk performance. The effect on milk yield of measures of climatic variables taken days earlier than the day that milk was recorded has been also investigated in dairy sheep. Finocchiaro *et al.* (2005) reported that the greatest decrease in daily milk yield 62.2 g (-3.9%) per unit of THI above a threshold value of THI=23 was observed for temperature and humidity records taken the day before milk recording in sheep. Table 1.3 summarizes the results of the estimated effects of heat stress on daily milk production in different species.

Table 1. 3. Estimated effect of heat stress on daily milk production in different species.

Species	Threshold THI	Estimated effect	Breed	Reference
Cattle[a]	75[1]	-3 %	Holstein	Bianca (1965)
	75[1]	-7 %	Jersey	
	75[1]	-2 %	Brown Swiss	
	83[2]	-31 %	Holstein	
	83[2]	-25 %	Jersey	
	83[2]	- 17 %	Brown Swiss	
	72	-0.76 %	Holstein	Ravagnolo *et al.* (2000)
	69	-2.05 %	Holstein	Bouraoui *et al.* (2002)
	72	-2.37 %	Holstein	West *et al.* (2003)
	72	-1.95 %	Jersey	
	68	-6.3 %	Holstein	Collier *et al.* (2011)
	71	-0.5 %	Holstein	Sánchez *et al.* (2009)
	72	-1.6 : -5.4 %	Croatia dairy cattle	Gantner *et al.* (2011)
Sheep[b]	23	-3.9%	Valle del Belice	Finocchiaro *et al.* (2005)
	45	-2.6 %	Merina de Grazalema	Menéndez-Buxadera *et al.* (2012b)

[1] at 29° C and 40 % humidity; [2] at 29° C and 90 % humidity.

[a] THI index was calculated with temperature measured in ºF; [b] THI index was calculated with temperature measured in ºC.

1. 5. Effect of heat stress on milk composition

Besides having an effect on milk yield, heat stress could also cause changes in milk composition. Working with two pairs of Jersey cows exposed to either 15 or 30 °C air temperature, Bandaranayaka and Holmes (1976) found that the fat and protein contents of milk decreased at 30 °C when intake was kept equal at both temperatures. McDowell *et al.* (1976) reported that when a lactating Holstein cow is transferred from an air temperature of 18 to 30 °C, milk fat, not-fat solids, and milk protein percentage decreased 39.7, 18.9 and 16.9%, respectively. Bouraoui *et al.* (2002) reported a decrease of daily fat (3.24 vs. 3.58 %) and protein (2.88 vs. 2.96 %) contents, as well as a decrease of daily fat (0.68 vs. 0.48 Kg) and protein (0.56 vs. 0.43 Kg) yields during summer with respect to spring period. Ravagnolo *et al.* (2000) observed a decline in fat yield when temperature increases even at air temperatures lowers than 24 °C (daily fat yield declines over the whole range of temperatures). This decline was slow until a THI value near 72, and then the average drop was of 0.012 kg per unit of THI. The same authors found that protein production seems to be constant up to a THI value about 72, which is also the end of the comfort zone for cows, then after that point the production drops near 0.009 kg per unit of THI.

Gentner *et al.* (2006) reported a slight decrease in daily fat and protein content as THI increase. However, Gentner *et al.* (2011) reported a highly significant decrease of daily fat and protein content when THI increase. In addition, Samolovac *et al.* (2012) observed that the lowest values for butterfat and protein contents (3.37 and 3.39% for butterfat and 3.15% for protein) were recorded in July and August, when the external temperatures, as well as the THI values, were the highest. The highest value for butterfat was 3.84%, registered in January and it was 3.37% for protein, registered in October and November. On the contrary, Knapp and Grummer (1991) found no significant decrease in fat content in milk from cows under heat stress. These different results could be caused by the use of total mixed rations, which probably alleviate milk fat depression commonly associated with heat stress by maintaining the intended intake ratio of forage to concentrate and so ensuring an adequate amount of fiber for proper rumen fermentation.

Finocchiaro *et al.* (2005) observed in Mediterranean dairy sheep a decrease of daily fat-plus-protein production of about 8.6 g (4.4%) per each unit increase of the THI value registered at the day before the test-day over the threshold of 23. However, they found that fat and protein contents were unaffected by heat stress, and no clear effect on these traits was observed for THI ≥ 23. Therefore, heat stress appears to reduce fat and protein yields in a similar proportion as it does milk yield, but not always their contents. Menéndez-Buxadera *et al.* (2012a) reported losses in fat plus protein yield, as a response to heat stress, which represent up to 1.9% and 3.1% of annual fat plus protein yields of Payoya and Murciano-Granadina dairy goats, respectively. Table 1.4 summarizes research results of estimated effect of heat stress on daily % of milk components in dairy cattle, sheep and goats.

Table 1. 4. Estimated effect of heat stress on milk components in different species.

Species	Threshold THI	Estimated effect on fat	Estimated effect on protein	Breed	Reference
Cattle[a]	72	-1.3 %	-1.05 %	Holstein	Ravagnolo *et al.* (2000)
	72	-0.67 : -2.0 %	-1.01 : -1.77 %	Croatia dairy cattle	Gantner *et al.* (2011)
Sheep[b]	23	-4.4 % fat + protein		Valle del Belice	Finocchiaro *et al.* (2005)
	29	-5.4 %	---	Manchega	Carabaño *et al.* (2013)
	28	---	-2.4 %	Manchega	
Goats[b]	25	-3.1 % fat + protein*		Murciano-Granadina	Menéndez-Buxadera *et al.* (2012a)
	28	-1.9 % fat + protein*		Payoya	
	20	-1.0 %	---	Florida	Carabaño *et al.* (2013)
	15	---	-0.9 %	Florida	

[a] THI index was calculated with temperature measured in °F; [b] THI index was calculated with temperature measured in °C; * annual yields.

1. 6. Genetic components of heat stress in dairy animals

As resistance to heat stress is a trait of major economic importance, especially in hot climatic regions, genetic studies had been performed to estimate genetic parameters for resistance to heat stress. Sánchez *et al.* (2009) provided evidence of individual variation for the onset of heat stress for daily milk yield in Holstein dairy cows. They used a model which assumed variation in both the slope and the onset of heat stress. Part of that variability was of genetic origin which, therefore, could be used for selecting animals for heat tolerance. In this study, the estimated heritability for milk yield in the absence of heat stress (THI = 60) was 0.17; it decreased to a minimum of 0.13 at THI=80 and then started to increase until reaching a maximum of 0.16 at a THI of 90. Similarly, Ravagnolo and Misztal (2000) found the genetic additive variance of the effect of heat stress on production traits to be zero at THI near 72 but it became high for THI values between 88 and 92. They also reported the genetic correlation between milk, fat or protein and heat tolerance to be around –0.3. Therefore, a continual selection for production without taking into account the side effect of heat tolerance results in decrease heat tolerance.

In this context, Menéndez-Buxadera *et al.* (2012a) reported the existence of an important amount of genetic variation for heat stress tolerance in Murciano-Granadina and

Payoya, two Spanish breeds of goats, which could be used for selection purposes. These authors defined different types of animals in respect to their responses to heat stress: (i) Robust animals, with constant estimated breeding values (EBV) throughout the range of THI values; (ii) tolerant animals, with EBV increasing when THI increase and (iii) non-tolerant animals, with EBV decreasing while THI grows. They also provided evidences for a relevant level of genotype of dairy traits by environment (THI) interaction, which indicates that selection for better milk performance will reduce heat stress tolerance. Moreover, Finocchiaro *et al.* (2005) confirmed the need of using heat resistant individuals in a sheep breeding program as one of the main strategies to improve animal welfare and productivity in hot climates, because the antagonistic genetics relation between milk yield traits and heat stress tolerance. Therefore, selecting animals only for yields will cause, in the long term, in animals with a lower heat stress tolerance.

1. 7. Climate over the Mediterranean basin

In biogeography, the Mediterranean basin refers to the lands around the Mediterranean sea that have a Mediterranean climate, with mild, rainy winters and hot, dry summers, which support characteristic Mediterranean forests, woodlands, and shrub vegetation (Köppen, 1936). Segnalini *et al*. (2011) referred to and delimited the Mediterranean basin by the 28° and 48° North parallels and the 10° West and 40° East meridians, and includes, fully or partially, over 20 countries. From a climatic perspective, the Mediterranean basin is recognized as a highly heterogeneous region and characterized by contrasting variations in temperature and precipitation between winter and summer, stemming from the descending branch of the Hadley circulation in summer while westerlies prevail during the winter season (Bolle, 2003), with dry tropical air from Saharan Africa, humid air mass coming from the Atlantic Ocean, and dynamic air mass over continental Europe (Lionello *et al.,* 2006) resulting in a variety of climate types between the hot and dry African climate regime in the south, and the mild and humid European climate in the north (Segnalini *et al.,* 2011). The effect of heat stress is substantial in the subtropical-Mediterranean zones, and farm animals raised in central and western Spain, or in the southern areas of France, Italy and Greece, are exposed annually for 3–5 months to considerable heat stress (Silanikove, 2000).

1. 8. Climatic change and future perspectives

The undesirable correlated negative effect of selection for milk traits on heat stress tolerance, manifested both in the threshold THI value at which production stars decreasing and the magnitude of such a reduction, becomes more important under the light of the predicted raising of air temperature as a result of global warming expectation and its effect on animal performance and adaptation. A climatic change leading to global warming, particularly in summer season, had been reported in several studies (Easterling *et al.*, 2007; IPCC, 2007; Sengnalini *et al.*, 2011 and 2013). Livestock production is potentially sensitive to climate change (Parry *et al.*, 2004; Sengnalini *et al.*, 2011). Heat stress has been already reported to be the cause of estimated annual economic losses of $0.9-$1.5 billion in the U.S. dairy sector (St-Pierre *et al*., 2003).

Sengnalini *et al.* (2011) studied the dynamics of the temperature-humidity index in Mediterranean basin and compared mean values of annual and seasonal THI calculated for three 30-year periods (1951-1980; 1961-1990 and 1971-2000). The comparison pointed out an overall warming in the Mediterranean area, and that the THI increase was particularly marked during summer (+0.27 units). Furthermore, by comparing the winter seasons, the THI slightly decreased during the study period (-0.03 units). The study also referred that the decade 1998-2007 showed a warming of the Mediterranean basin in terms of THI.

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the forecasted climate changes and extreme events are expected to have a dramatic impact on natural ecosystems and economy in many parts of the world (IPCC, 2007). The key conclusions of IPCC (2007) were: a) warming of the climatic system is unequivocal; b) anthropogenic warming will probably continue for centuries due to the timescales associated with climate processes and feedbacks; c) the surface air warming in the 21st century by best estimate will range from 1.1 to 2.9 °C in a “low warming scenario” and from 2.4 to 6.4 °C in a “high warming scenario”.

According to Easterling *et al.* (2007) the areas affected most by the global warming will be in the boreal hemisphere, in particular North America, Northern Europe, Northern Asia and, at a lower latitude, the Mediterranean basin and West-Central Asia. The Mediterranean basin has been categorized as a global warming hotspot (Giorgi and Bi 2005; Giorgi, 2006). IPCC (2007) reported that increased droughts and heat waves, especially during summer, are likely to dominate climate change impacts in Southern and Eastern Europe, while increased flooding and water logging in winter may dominate climate change impacts in the Northern part of the Mediterranean basin. Data collected and analyzed by Segnalini *et al.* (2013) revealed a gradual increase of both annual and seasonal THI during the period 1917-2050 and a strong heterogeneity of the Mediterranean area (figure 1.2). In particular, the analysis indicated that Spain, southern France and Italy should be expected to undergo the highest THI increase, which in 2041 - 2050 will range between 3 and 4 units. The area presents characteristics indicating risk of thermal stress for farm animals during summer months. The authors claim that at the end of the 2050, only northern Spain, France and Alpine regions are expected to have mean values of summer THI below the upper critical value of 68 (figure 1.3). Meanwhile, IPCC (2007) predicted an average rise in air temperature ranging from +2 °C to +6.5 °C by the end of the century, which is slightly higher than the world average increment estimated to range from +1.1 °C to +6.4 °C. As a result of their studies on the effects of climate changes on animal production and sustainability of livestock systems, Nardone *et al.* (2010) stated that the efforts on the selection of farm animals from now on must be oriented toward robustness and, above all, adaptability to heat stress.

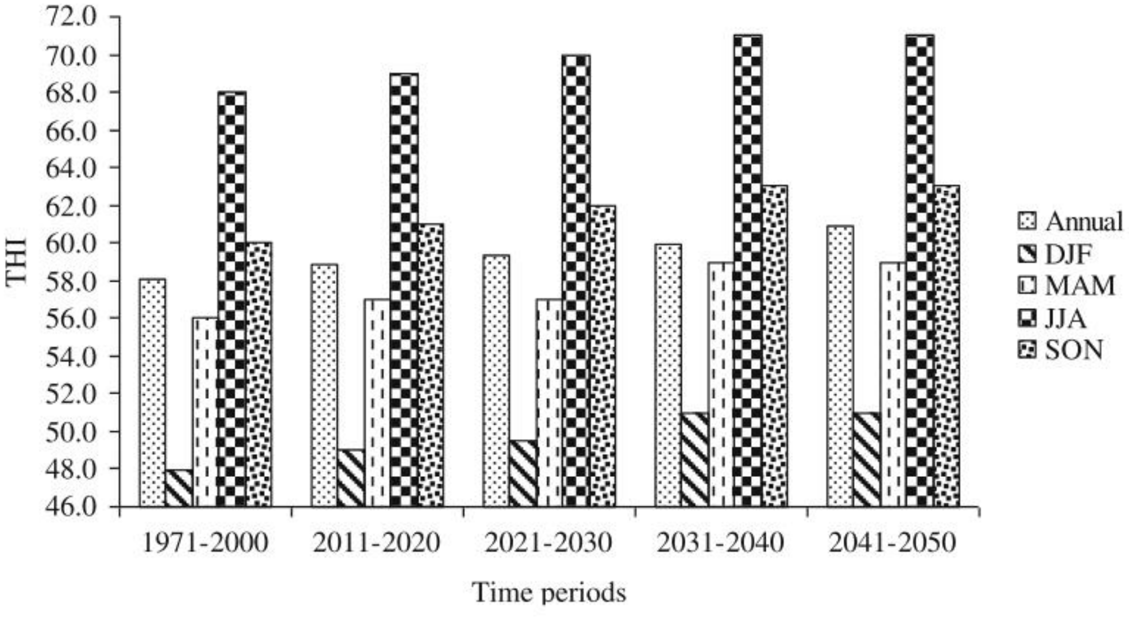


Figure 1. 2. Mean values of annual and seasonal THI calculated for the normal climate, 1971–2000 period, and for the four subsequent 2011–2020, 2021–2030, 2031–2040 and 2041–2050 decades in the Mediterranean area. Months of December, January, and February were considered as winter (DJF), March, April, and May as spring (MAM), June, July, and August as summer (JJA), and September, October, and November as fall (SON) (Segnalini *et al.*, 2013).

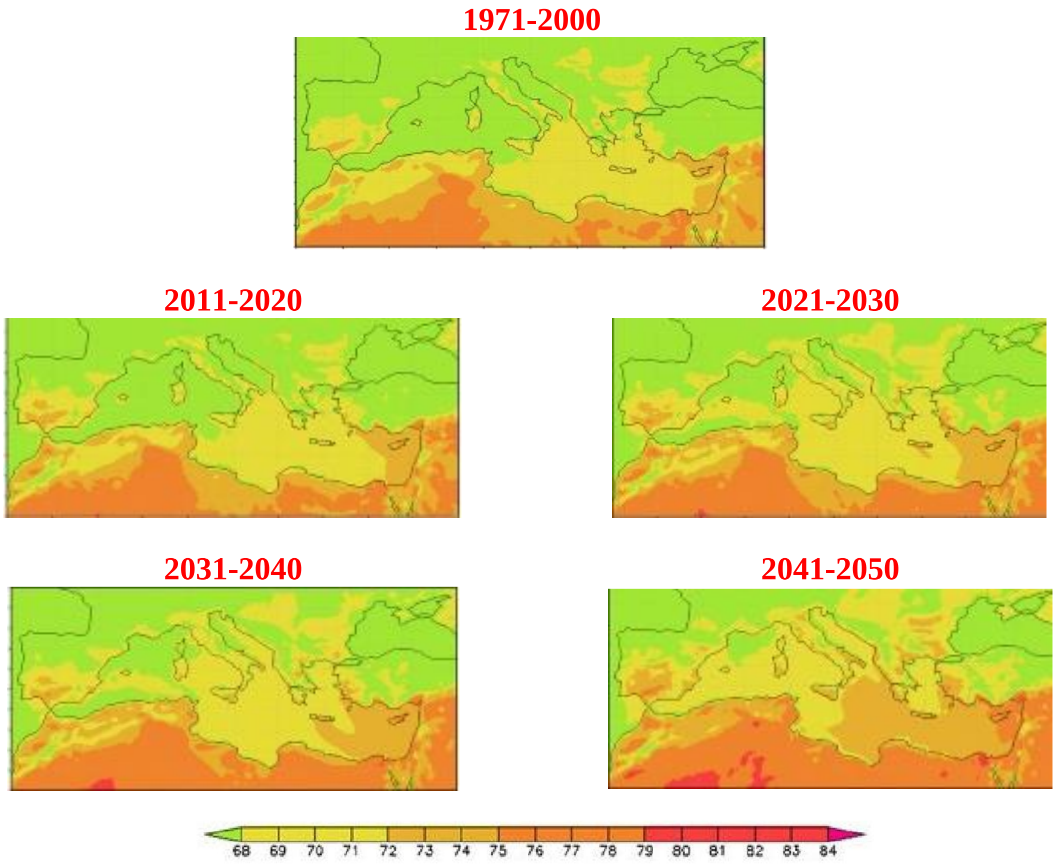


Figure 1. 3. Values of summer THI expressed in terms of livestock welfare categories for a normal climate, 1971–2000 period and for the subsequent 2011–2020, 2021–2030, 2031–2040, and 2041–2050 decades. Different colors correspond to the different livestock welfare categories; THI<68: no risk; 68≤THI<72: mild discomfort; 72≤THI<75: discomfort; 75≤THI<79: alert; 79≤THI<84: danger and THI≥84: emergency. (Segnalini *et al.*, 2013).

In order to develop appropriate adaptation strategies for the livestock sector in the Mediterranean countries, limiting the consequences of a decreased tolerance to heat stress as result of the combination of selection for productivity and climate change, the climatic variables most correlated to the production traits should be determined and the different tolerance thresholds and slopes of the productive responses to heat stress in each species and breed should be investigated.

1. 9. References

Armstrong, D.V. 1994. Heat stress interaction with shade and cooling. J. Dairy Sci., 7: 2044-2050.

Baker, R.L. and Gray, G.D. 2004. Appropriate breeds and breeding schemes for sheep and goats in the tropics. In: Worm Control for Small Ruminants in Tropical Asia. Eds. Sani, R.A.; Gray, G.D. and Baker, R.L. Canberra, ACIAR Monograph No. 113, pp. 63–96.

Bandaranayaka, D.D. and Holmes, C.W. 1976. Changes in the composition of milk and rumen contents in cows exposed to a high ambient temperature with controlled feeding. Trop. Anim. Health Prod., 8(1): 38-46.

Barker, J.S.F. 2009. Defining fitness in natural and domesticated population. In: Adaptation and Fitness in Animal Populations: Evolutionary and Breeding Perspectives on Genetic Resource Management. Eds. Van der Werf, J.H.J.; Graser, H.U.; Frankham, R. and Gondoro, C. Springer, New York, pp. 3-14.

Berman, A. 1968. Nychthemeral and seasonal patterns of thermoregulation in cattle. Aust. J. Agric. Res., 19: 181-189.

Berman, A.J. 2005. Estimates of heat stress relief needs for Holstein dairy cows. J. Anim. Sci., 83: 1377-1384.

Berry, I.L.; Shanklin, M.D. and Johnson, H.D. 1964. Dairy shelter design based on milk production decline as affected by temperature and humidity. Trans. Am. Soc. Agr. Eng., 7: 329–331.

Bianca, W. 1962. Relative importance of dry- and wet-bulb temperatures in causing heat stress in cattle. Nature, 195: 251–252.

Bianca, W. 1965. Reviews of the progress of dairy science. Section A. Physiology. Cattle in a hot environment. J. Dairy Res., 32: 291-345.

Bohmanova, J.; Misztal, I. and Colet, J.B. 2007. Temperature– humidity indices as indicators of milk production losses due to heat stress. J. Dairy Sci., 90: 1947–1956.

Bolle, H.J. 2003. Climate, climate variability and impacts in the Mediterranean area: an overview. In: Mediterranean Climate: Variability and Trends. Ed. Bolle, H.J. Springer, New York, pp. 5-86.

Bosen, J.F. 1959. Discomfort index. Reference Data Section, Air conditioning, heating and ventilation. American Society of Heating and Ventilating Engineers, Atlanta.

Bouraoui, R.; Lahmar, M.; Majdoub, A.; Djemali, M. and Belyea, R. 2002. The relationship of temperature-humidity index with milk production of dairy cows in a Mediterranean climate. Anim. Res., 51: 479-491.

Brouček, J.; Novák, P.; Vokřálová, J.; Šoch, M.; Kišac, P. and Uhrinčať, M. 2009. Effect of high temperature on milk production of cows from free-stall housing with natural ventilation. Slovak J. Anim. Sci., 42(4): 167-173.

Carabaño, M.J.; Ramón, M.; Abo-Shady, H.M.; Pérez-Guzmán, M.D.; Serrano, M.; Díaz, C.; Molina, A.; Menéndez-Buxadera, A.; Bahchaga, K.; Pérez-Cabal, M.A. and Serradilla, J.M. 2013. Estrés térmico en razas autóctonas de rumiantes lecheros. Proceedings of Jornadas sobre Producción Animal. Asociación Interprofesional para el Desarrollo Agrario (AIDA). XV(2): 451-452.

CGRFA. 2009. Contributions of smallholder farmers & pastoralists to the development, use and conservation of animal genetic resources. Commission on genetic resources for food and agriculture. Intergovernmental technical working group on animal genetic resources for food and agriculture. Fifth Session, 28-30 January 2009. Roma. CGRFA/WG-angr-5/09/Inf.4, 40 Pp.

Collier, R.J.; Zimbelman, R.B.; Rhoads, R.P.; Rhoads, M.L. and Baumgard, L.H. 2011. A re-evaluation of the impact of Temperature Humidity Index (THI) and Black Globe Humidity Index (BGHI) on milk production in high producing dairy cows. Western Dairy Management Conference. Reno, NV. pp. 113-125.

Coppock, C.E.; Grant, P.A.; Portzer, S.J.; Charles, D.A. and Escobosa, A. 1982. Lactating dairy cow responses to dietary sodium, chloride, and bicarbonate during hot weather. J. Dairy Sci., 65: 566–576.

Curtis, S.E. 1983. Environmental Management in Animal Agriculture. Iowa State Press, USA. Ames, Iowa. pp. 266 – 268.

Du Preez, J.H.; Giesecke, W.H. and Hattingh, P.J. 1990a. Heat stress in dairy cattle and other livestock under Southern African conditions. I. Temperature-humidity index mean values during the four main seasons. Onderstepoort J. Vet. Res., 57: 77-86.

Du Preez, J.H.; Hatting, P.J.; Giesecke, W.H. and Eisenberg, B.E. 1990b. Heat stress in dairy cattle and other livestock under Southern African conditions. III. Monthly temperature-humidity index mean values and their significance in the performance of dairy cattle, Onderstepoort J. Vet. Res., 57: 243–248.

Easterling, W.E.; Aggarwal, P.K.; Batima, P.; Brander, K.M.; Erda, L.; Howden, S.M.; Kirilenko, A.; Morton, J.; Soussana, J.F.; Schmidhuber, J. and Tubiello, F.N. 2007. Food, fibre and forest products. Climate Change 2007: Impacts, Adaptation and Vulnerability. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 273–313.

FAO, Food and Agriculture Organizations for the United States. 2013. FAO Statistics Division.
http://faostat.fao.org/site/569/DesktopDefault.aspx?PageID=569#ancor

Farooq, U.; Samad, H.A.; Shehzad, F. and Qayyum, A. 2010. Physiological responses of cattle to heat stress. World Applied Sciences Journal 8 (Special Issue of Biotechnology & Genetic Engineering): 38-43.

Finch, V.A. 1984. Heat as a stress factor in herbivores under tropical conditions. In: Herbivore Nutrition in the Subtropics and Tropics. Eds. Gilchrist, F.M.C. and Mackie, R.I. The Science Press, Graighall, South Africa, pp. 89–105.

Finocchiaro, R.; Van Kaam, J.B.C.H.M.; Portolano, B. and Misztal, I. 2005. Effect of heat stress on production of Mediterranean dairy sheep. J. Dairy Sci., 88: 1855–1864.

Fregley, M.J. 1996. Adaptations: some general characteristics. In: Fregley, M.J., Blatteis, C.M. (Eds.), Handbook of Physiology, Section 4: Environmental Physiology, Vol. I. Oxford University Press, pp. 3–15.

Gantner, V.; Kuterovac, K.; Jovanovac, S.; Klopčić, M. and Solić, D. 2006. Effect of temperature-humidity index on daily milk yield of dairy cows. Acta Agraria Kaposvàriensis, 10(2): 113-119.

Gantner, V.; Mijić, P.; Kuterovac, K.; Solić, D. and Gantner, R. 2011. Temperature-humidity index values and their significance on the daily production of dairy cattle. Daily production of dairy cattle. Mljekarstvo, 61(1): 56-63.

Giorgi, F. 2006. Climate change hot-spots. Geophys. Res. Lett., 33: L08707.

Giorgi, F. and Bi, X. 2005. Update regional precipitation and temperature changes for the 21st century from ensembles of recent AOGCM simulations. Geophys. Res. Lett., 32: L21715.

Hahn, G.L.; Mader, T.L. and Eigenberg, R.A. 2003. Perspective on development of thermal indices for animal studies and management. Technical series, 7: 31–44.

Herbut, P. and Angrecka, S. 2012. Forming of temperature-humidity index (THI) and milk production of cows in the free-stall barn during the period of summer heat. Animal Science Papers and Reports, 30(4): 363-372.

IPCC, Intergovernmental Panel on Climate Change. 2007. Climate change 2007. Physical Science Basis, Cambridge. pp. 989.

Johnson, H.D. 1980. Environmental management of cattle to minimize the stress of climate changes. Int. J. Biometeor., 24(Suppl. 7, Part 2): 65-78.

Johnson, H.D. 1987. Bioclimates and livestock. In: World Animal Science B5 Bioclimatology and the adaptation of Livestock. Ed. Johnson, H.D. Elsevier Science Publishers B.V., Amsterdam, Netherlands, pp. 3-16.

Johnson, H.D.; Shanklin, M.D. and Hahn, L. 1988. Productive adaptability of Holstein cows to environmental heat. Missouri Agric. Exp. Sta. Res. Bull., p. 1060.

Johnson, H.D.; Kibler, H.H.; Ragsdale, A.C.; Berryil, E. and Shanklin, P. 1961. Role of heat tolerance and production level in response of lactating Holsteins to various temperature-humidity conditions. J. Dairy Sci., 44: 1191-1199.

Johnson, H.D.; Ragsdale, A.C.; Berry, I.L. and Shanklin, M.D. 1962. Effect of various temperature humidity combinations on milk production of Holstein cattle. Missouri Agric. Exp. Sta. Res. Bull., 791: 1–39.

Kadzere, C.T.; Murphy, M.R.; Silanikove, N. and Maltz, E. 2002. Heat stress in lactating dairy cows: a review. Livest. Prod. Sci., 77: 59-91.

Kelly, C.F. and Bond, T.E. 1971. Bioclimatic factors and their measurement: A guide to environmental research on animals. National Academy of Sciences, Washington, DC. pp. 71-92.

Kibler, H.H. 1964. Environmental physiology and shelter engineering. LXVII. Thermal effects of various temperature-humidity combinations on Holstein cattle as measured by eight physiological responses. Missouri Agric. Exp. Sta. Res. Bull., p. 862.

Knapp, D.M. and Grummer, R.R. 1991. Response of lactating dairy cows to fat supplementation during heat stress. J. Dairy Sci., 74: 2573-2579.

Köppen, W. 1936. Das geographische aystem der klimate. In: Handbuch der Klimatologie, Bd 1. Eds. Köppen, W and Geiger. R. Gebr Borntrger, Berlin, pp. C1-C44.

Lacetera, N.; Bernabucci, U.; Ronchi, B. and Nardone, A. 2003. Physiological and productive consequences of heat stress. The case of dairy ruminants. In: Proc. of the Symposiumon Interaction between Climate and Animal Production: EAAP Technical Series. Eds. Lacetera, N.; Bernabucci, U.; Khalifa, H.H.; Ronchi, B. and Nardone, A. Viterbo 7, pp. 45–60.

Lee, D.H.K. 1965. Climatic stress indices for domestic animals. Int. J. Biometeorol., 9: 29–35.

Lionello, P.; Malanotte-Rizzoli, P.; Boscolo, R.; Alpert, P.; Artale, V.; Li, L.; Luterbacher, J.; May, W.; Trigo, R.; Tsimplis, M.; Ulbrich, U. and Xoplaki, E. 2006. The Mediterranean climate: an overview of the main characteristics and issues. In: Mediterranean climate variability. Eds. Lionello, P.; Malanotte-Rizzoli, P. and Boscolo, R. Elsevier, Amsterdam, pp. 1–26.

LPHSI, Livestock and Poultry Heat Stress Indices. 1990. Agricultural Engineering Technology Guide, Clemson University, Clemson SC, 29634, USA.

Mader, T.L.; Davis, M.S. and Brown-Brandl, T. 2006. Environmental factors influencing heat stress in feedlot cattle. J. Anim. Sci., 84: 712–719.

Marai, I.F.M. and Haeeb, A.A.M. 2010. Buffalo's biological functions as affected by heat stress. A review. Livest. Sci., 127: 89–109.

Marai, I.F.M.; Ayyat, M.S. and Abd El-Monem, U.M. 2001. Growth performance and reproductive traits at first parity of New Zealand White female rabbits as affected by heat stress and its alleviation, under Egyptian conditions. Trop. Anim. Health Prod., 33: 457–462.

Marai, I.F.M.; El-Darawany, A.A.; Fadiel, A. and Abdel-Hafez, M.A.M. 2007. Physiological traits as affected by heat stress in sheep: a review. Small Rumin. Res., 71: 1–12.

McDowell, R.E.; Hooven, N.W. and Camoens, J.K. 1976. Effects of climate on performance of Holsteins in first lactation. J. Dairy Sci., 59: 965‒973.

Menéndez-Buxadera, A.; Molina, A.; Arrebola, F.; Clemente, I. and Serradilla, J.M. 2012a. Genetic variation of adaptation to heat stress in two Spanish dairy goat breeds. J. Anim. Breed. Genet., 129: 306-315.

Menéndez-Buxadera, A.; Castro, J.A.; Medina, C.; Osorio, J.; Torres, R.; Serradilla, J.M. and Molina, A. 2012b. Estudio preliminar del efecto del estrés térmico en la producción lechera de la raza Merina de Grazalema. MG-FEAGAS, 37: 131-141.

Mirkena, T.; Duguma, G.; Haile, A.; Tibbo, M.; Okeyo, A.M.; Wurzinger, M. and Sölkner, J. 2010. Genetics of adaptation in domestic farm animals: A review. Livest. Sci., 132: 1–12.

Muller, C.J.C. and Botha, J.A. 1993. Effect of summer climatic conditions on different heat tolerance indicators in primiparous Friesian and Jersey cows. S. Afr. J. Anim. Sci., 23: 98-103.

Nardone, A.; Ronchi, B.; Lacetera, N.; Ranieri, M.S. and Bernabucci, U. 2010. Effects of climate changes on animal production and sustainability of livestock systems. Livest. Sci., 130: 57–69.

NOAA, National Oceanic and Atmospheric Administration. 1976. “Livestock Hot Weather Stress.” US. Dept. Commerce, Natl. Whether Serv Central Reg., Reg. Operations Manual Lett., pp. C31-C76.

NRC, National Research Council. 1971. A guide to environmental research on animals. National Academy of Sciences, Washington, DC. pp. 274.

Oseni, S. and Bebe, O. 2010. Climate change, genetics of adaptation and livestock production in low-input systems. 2nd International Conference: Climate, Sustainability and Development in Semi-arid Regions. Fortaleza - Ceará, Brazil, pp. 12.

Parry, M.L.; Rosenzweig, C.; Iglesias, A.; Livermore, M. and Fischer, G. 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Global Environmental Change, 14(1): 53-67.

Prayaga, K.C. and Henshall, J.M. 2005. Adaptability in tropical beef cattle: genetic parameters of growth, adaptive and temperament traits in a crossbred population. Aust. J. Exp. Agri., 45: 971–983.

Purwanto, B.P.; Abo, Y.; Sakamoto, R.; Furumoto, F. and Yamamoto, S. 1990. Diurnal patterns of heat production and heart rate under thermoneutral conditions in Holstein Friesian cows differing in milk production. J. Agric. Sci., 114: 139-142.

Rauw, W.M.; Kanis, E.; Noordhuizen-Stassen, E.N. and Grommers, F.J. 1998. Undesirable side effects of selection for high production efficiency in farm animals: a review. Livest. Prod. Sci., 56: 15–33.

Ravagnolo, O. and Misztal, I. 2000. Genetic component of heat stress in dairy cattle, parameter estimation. J. Dairy Sci., 83: 2126–2130**.**

Ravagnolo, O.; Misztal, I. and Hoogenboom, G. 2000. Genetic Component of Heat Stress in Dairy Cattle, Development of Heat Index Function. J. Dairy Sci., 83: 2120–2125.

Samolovac, L.; Stojic, P.; Beskorovajni, R. and Jovanovic, M. 2012. Temperature and humidity as stress factors in milk production. Proceedings Third International Scientific Symposium "Agrosym Jahorina 2012", pp. 466-471.

Sánchez, J.P.; Misztal, I.; Aguilar, I.; Zumbach, B. and Rekaya, R. 2009. Genetic determination of the onset of heat stress on daily milk production in the US Holstein cattle. J. Dairy Sci., 92: 4035–4045.

Segnalini, M.; Nardone, A.; Bernabucci, U.; Vitali, A.; Ronchi, B. and Lacetera, N. 2011. Dynamics of the temperature-humidity index in the Mediterranean basin. Int. J. Biometeorol., 55: 253–263.

Segnalini, M.; Bernabucci, U.; Vitali, A.; Nardone, A. and Lacetera, N. 2013. Temperature humidity index scenarios in the Mediterranean basin. Int. J. Biometeorol., 57(3): 451-458.

Sevi, A. and Caroprese, M. 2012. Impact of heat stress on milk production, immunity and udder health in sheep: A critical review. Small Rum. Res., 107: 1–7.

Sevi, A.; Annicchiarico, G.; Albenzio, M.; Taibi, L.; Muscio, A. and Dell'Aquila, S. 2001. Effects of solar radiation and feeding time on behavior immune response and production of lactating ewes under high ambient temperature. J. Dairy Sci., 84: 629–640.

Silanikove, N. 1997. Why goats raised on harsh environment perform better than other domesticated animals. Options Méditerranéennes, 34 (Ser. A): 185–194.

Silanikove, N. 2000. Effects of heat stress on the welfare of extensively managed domestic ruminants. Livest. Product. Sci., 67: 1–18.

Srikandakumar, A.; Johnson, E.H. and Mahgoub, O. 2003. Effect of heat stress on respiratory rate, rectal temperature and blood chemistry in Omani and Australian Merino sheep. Small Rum. Res., 49: 193–198.

St-Pierre, N.R.; Cobanov, B. and Schnitkey, G. 2003. Economic losses from heat stress by US livestock industries. J. Dairy Sci., 86(E Suppl.): E52–E77.

Taylor, R.E. 1992. Adaptation to the environment. In: Scientific Farm Animal Production, 4th ed. Macmillan Publishing Company, New York, pp. 326–332.

Thom, E.C. 1958. Cooling degrees: day air-conditioning, heating and ventilating. Trans. Am. Soc. Heat, 55: 65–69.

Thom, E.C. 1959. The discomfort index. Weatherwise, 12: 57–60.

West, J.W. 2003. Effects of heat-stress on production in dairy cattle. J. Dairy Sci., 86: 2131-2144.

West, J.W.; Mullinix, B.G. and Bernard, J.K. 2003. Effects of hot, humid weather on milk temperature, dry matter intake, and milk yield of lactating dairy cows. J. Dairy Sci., 86: 232–242.

Wiersma, F. 1990. THI for dairy cows. Department of Agricultural Engineer, The University of Arizona, Tuscon, AZ.

Yousef, M.K. 1985. Stress physiology in livestock. CRC Press, Boca Raton, FL. pp. 47-54.

CHAPTER 2

Effect of different climatic variables on dairy traits of Florida goats

2. 1. Abstract

A total of 185,675 test-day records belonging to 13,481 lactating goats in 20 flocks were used to study heat stress in Spanish dairy goats (Florida breed), examining and determining the climatic variables most correlated to dairy traits and estimating the tolerance threshold and slope of the response of these traits to heat stress. The productive traits investigated were daily milk, fat, protein and fat plus protein yields and fat and protein contents. Test day monthly records from each herd were merged with the corresponding meteorological data registered in the nearest weather station. The meteorological data used for the heat stress analyses were maximum and average daily temperature and a temperature-humidity index (THI) registered the day of milk recording, one day and two days before. A ridge regression analysis and a GLM select analysis were carried out to select the climatic variables and the dates which were recorded having the highest relations with milk records corrected for significant fixed systematic and permanent environmental effects. Subsequently, in order to estimate the tolerance threshold and the slope of the production response to heat stress, a model including systematic fixed effects, the random animal effect, the linear regression coefficient and the threshold of thermo tolerance of the selected climatic variables for each dairy trait was performed using Bayesian methods. Furthermore, to better fit and understand the relation between selected climatic variables and dairy traits, models with the same fixed and random effects considered formerly and a polynomial regression between milk traits and each climatic variable were tested. All analyses were made with five data set: all data; data from high milk yielding goats and data from low milk yielding goats, chosen for their values of milk yield per lactation over and below 1.5 standard deviations of the population mean, respectively and data from the warm season period (with records from April till September) and cold season period (with records from October till March). Results showed that maximum and average temperatures explain the change in dairy traits caused by climatic effects better than THI index. Temperatures registered the day of milk recording or one day before have more effect on the traits studied than those registered two days before. No climatic variables had a significant effect on fat, protein and fat plus protein yield in low productive animals. Polynomial models fitted and explained better the production pattern than the linear regression models. Generally, daily milk yield increased parallel to the increase in temperature. However, daily fat, protein and fat plus protein yields and fat and protein contents decrease when temperature increase. Results indicate that on the contrary to what has been observed in dairy cattle, Florida goats do not show what has been called a "comfortable" zone in which milk and milk components yields keep constant through the range of THI values and the decreases of fat and protein yields and of fat and protein contents start at relatively low temperature.

2. 2. Introduction

Environment has a great positive or negative impact on animal production. The component of animal environmental factors included ambient temperature, air moisture, photoperiod, altitude, radiation, wind, etc. Out of all these factors, thermal environment/heat stress is the most detrimental to animal production especially in dairy ruminants. Thermal environment has been reported to be a major factor that can negatively affect milk production and it is considered one of the main causes of economic losses in animal production (St-Pierre *et al.*, 2003). Most efforts in the selection of dairy animals have been placed on the improvement of milk yield and composition. As the productive capacity of dairy animals improved, metabolic heat production increased (West *et al.*, 2003) and heat tolerance decreased (Johnson *et al.*, 1962). Consequently, heat stress has become one of the most limiting factors of dairy production in certain areas. However, only recently more attention starts to be paid to the possible genetic improvement of thermoregulatory ability.

As a measure of the level of heat stress, climatic variables like maximum, minimum and average temperatures (T) and relative humidity (RH), have been frequently used to indicate the degree of stress and to determine their influence on dairy animal. However, most researchers have used an index call THI as a measure of the combined effect of temperature and humidity to measure the level of heat stress (Bianca, 1962; NRC, 1971). As THI values increase, animal performance declines, and these declines have been said to be subjected to a threshold response, a point after which ambient temperatures exceed an animal's thermo neutral zone and performance begins to drop. For dairy cattle, a threshold around 72 THI, which corresponds to 22°C at 100% humidity, has been observed (Du Preez *et al.*, 1990; Ravagnolo *et al.*, 2000). Sheep and goats are thought to be the more resistant species to extreme climatic conditions among the domestic ruminants. Besides, indigenous breeds of ruminants from tropical and subtropical regions generally are better adapted to harsh hot environments than their counterparts from more temperate zones (Finch, 1984). However, few researches have been carried out to study if there is a thermo neutral zone and a tolerance threshold in sheep and goats. Moreover, Carabaño *et al.* (2013) compared between the effect of THI index, maximum and average temperature on dairy traits for both Manchega sheep and Florida goats and they reported that average and maximum temperature models were best fitted.

The Mediterranean basin is recognized as a highly heterogeneous region and it is characterized by contrasting variation in temperature and rainfall from winter to summer (Bolle, 2003). The effect of heat stress is substantial in many Mediterranean zones. Farm animals raised in central and western Spain, or in the southern areas of France, Italy and Greece, for example, are exposed annually to 3–5 months of considerable heat stress (Silanikove, 2000). Therefore, improved description of the effects of climatic variables on milk yield and milk composition for Mediterranean dairy animals, especially small ruminant, are needed to better predict the effects of seasonal heat stress. The aim of this study was to determine the climatic variables most correlated to dairy traits and to estimate the tolerance threshold and the slope of productive response to heat stress in one of the native Spanish breeds of goats (Florida) raised in Andalusia, one of the regions of the Mediterranean basin with warm summers.

2. 3. Materials and Methods

A total of 185,675 test-day records of Florida dairy goats, collected between January 2006 and February 2012, were used as initial data set to investigate and determine the climatic variables most correlated to the production data and to estimate the tolerance threshold and slope of the response of dairy traits to these climatic variables. Data were provided by the Asociación Nacional de Criadores de Ganado Caprino de Raza Florida (ACRIFLOR) and corresponded to 13,481 lactating goats in 20 flocks including daily milk yield, daily fat percentage and daily protein percentage, registered according to ICAR standards (BOE, 2005). Subsequently, daily fat, protein and daily fat plus protein yields were calculated. Records from lactations longer than 240 days and lower than 10 days were deleted. Meteorological data set consisted of daily maximum and minimum temperatures (T, °C) and relative humidity (RH, %) registered in the meteorological station nearest each farm (<22 Km). These data were provided by the “Agencia Estatal de Meteorología (AEMET)” and the “Sistema de Información Agroclimática para el Regadío

(SiAR)" belonging to the Spanish Ministry of Agriculture, Food and Environment. Subsequently, daily mean temperature and mean relative humidity were calculated averaging maximum and minimum values. An index of temperature and relative humidity (THI) combining maximum temperature (°C) and average relative humidity (%), proposed by Kelly and Bond (1971), was calculated following the adaptation to Mediterranean climatic conditions of Finocchiaro *et al.* (2005):

$$THI= [T-(0.55\times(1-RH))\times(T-14.4)],$$

where, T is maximum temperature (°C) and RH is average relative humidity

Values of this THI for different combination of temperature (°C) and relative humidity (%) are given in Table 2.1 (values of THI at which heat stress are expected according to Finocchiaro *et al.* (2005) are marked in red). For a constant temperature under 14° C, higher relative humidity values give origin to lower THI values. By contrary, for temperature over 15° C, higher relative humidity values cause higher THI values for the same temperature.

Descriptive statistics of weather data used in this study are shown in Table 2.2. Figure 2.1 shows the variation throughout the year of average values of THI, maximum temperature (Tmax) and average relative humidity (RHave).

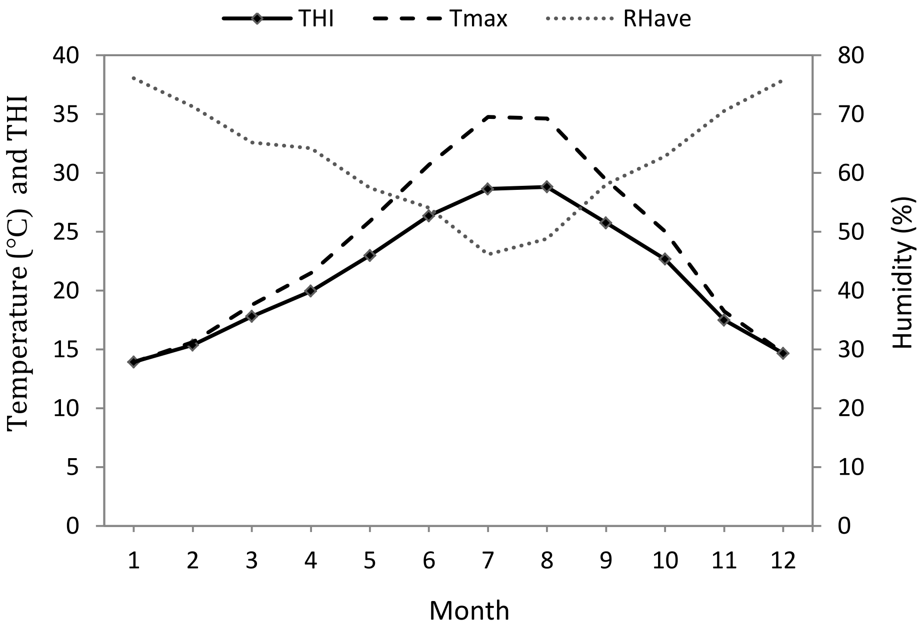


Figure 2.1. Variation through the year of average values of THI index, maximum temperature (Tmax) and average relative humidity (RHave).

Table 2. 1. THI indices for different combination of maximum temperature (T °C) and average relative humidity (RH%) using Finocchiaro *et al.* (2005) equation with THI vales of heat stress marked in red.

T /RH	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
0	8	8	7	7	6	6	6	5	5	4	4	4	3	3	2	2	2	1	1	0	0
1	8	8	8	7	7	7	6	6	5	5	5	4	4	4	3	3	2	2	2	1	1
2	9	8	8	8	7	7	7	6	6	6	5	5	5	4	4	4	3	3	3	2	2
3	9	9	9	8	8	8	7	7	7	6	6	6	6	5	5	5	4	4	4	3	3
4	10	9	9	9	9	8	8	8	7	7	7	7	6	6	6	5	5	5	5	4	4
5	10	10	10	9	9	9	9	8	8	8	8	7	7	7	7	6	6	6	6	5	5
6	11	10	10	10	10	9	9	9	9	9	8	8	8	8	7	7	7	7	6	6	6
7	11	11	11	10	10	10	10	10	9	9	9	9	9	8	8	8	8	8	7	7	7
8	12	11	11	11	11	11	10	10	10	10	10	10	9	9	9	9	9	9	8	8	8
9	12	12	12	12	11	11	11	11	11	11	10	10	10	10	10	10	10	9	9	9	9
10	12	12	12	12	12	12	12	12	11	11	11	11	11	11	11	11	10	10	10	10	10
11	13	13	13	13	12	12	12	12	12	12	12	12	12	12	12	11	11	11	11	11	11
12	13	13	13	13	13	13	13	13	13	13	13	13	13	12	12	12	12	12	12	12	12
13	14	14	14	14	14	14	14	14	13	13	13	13	13	13	13	13	13	13	13	13	13
14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
16	15	15	15	15	15	15	15	15	15	16	16	16	16	16	16	16	16	16	16	16	16
17	16	16	16	16	16	16	16	16	16	16	16	16	16	16	17	17	17	17	17	17	17
18	16	16	16	16	16	17	17	17	17	17	17	17	17	17	17	18	18	18	18	18	18
19	16	17	17	17	17	17	17	17	17	18	18	18	18	18	18	18	18	19	19	19	19
20	17	17	17	17	18	18	18	18	18	18	18	19	19	19	19	19	19	20	20	20	20
21	17	18	18	18	18	18	18	19	19	19	19	19	20	20	20	20	20	20	21	21	21
22	18	18	18	18	19	19	19	19	19	20	20	20	20	21	21	21	21	21	22	22	22
23	18	19	19	19	19	19	20	20	20	20	21	21	21	21	22	22	22	22	23	23	23
24	19	19	19	20	20	20	20	21	21	21	21	22	22	22	22	23	23	23	23	24	24
25	19	19	20	20	20	21	21	21	22	22	22	22	23	23	23	24	24	24	24	25	25
26	20	20	20	21	21	21	22	22	22	22	23	23	23	24	24	24	25	25	25	26	26
27	20	20	21	21	21	22	22	22	23	23	24	24	24	25	25	25	26	26	26	27	27
28	21	21	21	22	22	22	23	23	24	24	24	25	25	25	26	26	27	27	27	28	28
29	21	21	22	22	23	23	23	24	24	25	25	25	26	26	27	27	27	28	28	29	29
30	21	22	22	23	23	24	24	24	25	25	26	26	27	27	27	28	28	29	29	30	30
31	22	22	23	23	24	24	25	25	26	26	26	27	27	28	28	29	29	30	30	31	31
32	22	23	23	24	24	25	25	26	26	27	27	28	28	29	29	30	30	31	31	32	32
33	23	23	24	24	25	25	26	26	27	27	28	28	29	29	30	30	31	31	32	32	33
34	23	24	24	25	25	26	26	27	28	28	29	29	30	30	31	31	32	32	33	33	34
35	24	24	25	25	26	27	27	28	28	29	29	30	30	31	32	32	33	33	34	34	35
36	24	25	25	26	26	27	28	28	29	29	30	31	31	32	32	33	34	34	35	35	36
37	25	25	26	26	27	28	28	29	30	30	31	31	32	33	33	34	35	35	36	36	37
38	25	26	26	27	28	28	29	30	30	31	32	32	33	33	34	35	35	36	37	37	38
39	25	26	27	27	28	29	30	30	31	32	32	33	34	34	35	36	36	37	38	38	39
40	26	27	27	28	29	29	30	31	32	32	33	34	34	35	36	36	37	38	39	39	40
41	26	27	28	29	29	30	31	31	32	33	34	34	35	36	37	37	38	39	40	40	41
42	27	28	28	29	30	31	31	32	33	34	34	35	36	37	37	38	39	40	40	41	42
43	27	28	29	30	30	31	32	33	34	34	35	36	37	37	38	39	40	41	41	42	43
44	28	29	29	30	31	32	33	33	34	35	36	37	37	38	39	40	41	42	42	43	44
45	28	29	30	31	32	32	33	34	35	36	37	37	38	39	40	41	42	42	43	44	45

Table 2. 2. Descriptive statistics of weather data.

Daily measurement	Mean ± SD
Maximum temperature (°C)	23.7±8.4
Minimum temperature (°C)	11.4±6.3
Average temperature (°C)	17.6±7.1
Maximum relative humidity (%)	83.7±14.4
Minimum Relative humidity (%)	41.1±19.5
Average relative humidity (%)	62.4±15.6
Temperature-humidity index	21.3±6.1

Daily production and meteorological data were merged, resulting in 100,787 test-day records of 10,283 lactating goats in 20 flocks, each one with its corresponding climatic data. Five data sets were independently analyzed. The first consisted in the complete data set formerly described. The second and third data sets had only the data from goats having a cumulated yield during the whole lactation 1.5 standard deviations over the mean (high yielding goats, HP) and 1.5 standard deviations under the mean (low yielding goats, LP), respectively. The fourth and fifth data sets contained data recorded during the warm season (from April till September) and the cold season (from October till March), respectively. Table 2.3 shows a summary of the basic statistics of these data sets.

Table 2. 3. Number of records and descriptive statistics for the total (TP), high yielding (HP), low yielding (LP), warm (HS) and cold season (CS) data sets.

	TP	HP	LP	HS	CS
N. records	100787	22476	3488	53328	47507
N. animals	10283	1538	357	9744	9531
N. flocks	20	19	20	20	20
Milk yield (g)	2351±1089	3025±1201	1844±940	2285±1031	2426±1146
Protein content(%)	3.33±0.57	3.26±0.55	3.38±0.61	3.20±0.53	3.47±0.57
Protein yield (g)	72.29±37.81	90.41±43.37	57.77±32.34	67.78±34.46	77.36±40.64
Fat content (%)	5.00±1.39	4.78±1.32	5.16±1.45	4.67±1.22	5.38±1.46
Fat yield (g)	106.45±56.21	130.41±63.45	86.19±49.23	97.04±50.39	117.01±60.38
Fat+Protein (g)	191.60±82.13	238.83±87.81	154.43±72.38	176.54±73.50	208.51±87.83

Statistical analysis

The following general linear model (SAS, 2009) was used in a first step to determine the fixed factors significantly affecting the dependent variables:

$$y_{ijkl} = \mu + \mathrm{HY}_i + \mathrm{ALS}_j + \mathrm{M}_k + e_{ijkl}$$

where, y_{ijkl} is the observed dependent variable for each trait, μ is parametric mean of the population; HY is the effect of herd-year of lactation (92 levels); ALS is the effect of the age-lactation number-stage (month) of lactation (256 levels); M is the effect of milking frequency (2 levels) and e is the residual variance.

Data was then corrected for the significant systematic fixed effect (herd-year of lactation, age-lactation number-stage of lactation and milking frequency) and for random animal effect (actually permanent environmental effect, because the relationship matrix was not considered in the analysis) using mixed model procedure of SAS (2009).

A ridge regression analysis between productive and climatic variables was carried out with corrected data using R subroutines in order to know the phenotypic response of the traits under study along the trajectory of heat stress. Besides that, climatic variables (THI, average and maximum temperatures registered at the test day and one and two days before) most correlated to different daily production variables (milk, fat, protein and fat plus protein yields and fat and protein contents) were determined using three models (model for each climatic variable; THI, average and maximum temperature) with the GLMSELECT procedure of SAS program. The best fitted model was chosen using Schwarz's Bayesian criterion (SBC) criteria. An estimation of linear regression was performed to climatic variables of the selected model for each production variable and finally the most correlated climatic variable was chosen for each daily production variable.

Besides, an analysis was made to estimate the tolerance threshold and the slope of the genetic response to heat stress with the following spline model:

$$y_{ijkno} = \mathrm{HY}_i + \mathrm{ALS}_j + \mathrm{M}_k + \mathrm{b} \times \mathrm{f(t)} + a_n + e_{ijkno}$$

where, y_{ijkno} is the observed dependent variable for each trait; HY, ALS and M are the fixed effects formerly defined; b is the regression coefficient of the trait on the climatic variable t (temperature or THI) with f(t)=0 if t< T_o and f(t)=T-T_o if else, being T_o the tolerance threshold; a is the random animal effect with var(a)=$\mathbf{I}\sigma_a^2$ and e is the residual with var(e) = $\mathbf{I}\sigma_e^2$. The methodology used to estimate these parameters was Bayesian MCMC methods, and more specifically, Gibbs sampling. The chosen model was a hierarchical model that estimated values of T_0, β, var_a y var_e. Threshold value was estimated by Metropolis-Hasting sampling from a normal distribution centered on the actual value of the threshold (the initial value of T_0 was set to 35 ° C). This procedure was repeated for 10,000 iterations with an initial burn-in 2000. Post-Gibbs analysis was performed using boa package of R. For each parameter, the mean, the standard deviation, the error (standard) Monte Carlo (MC error) and the high posterior density intervals (HPD95%) were calculated.

Since former models did not fit well the real response of production traits to heat stress, the following polynomial model was additionally tested:

$$y_{ijklno} = \mathrm{HY}_i + \mathrm{ALS}_j + \mathrm{M}_k + \sum_{r=0}^{s} \Phi_r b_{lr} \,.\, \mathrm{f(t)} + a_n + e_{ijklno}$$

where, all terms were the same as in previous model except that the regression coefficient (b) of the trait on the climatic variable t (temperature or THI) was calculated as a fixed second or third (s = 2 or 3) order Legendre polynomial coefficients and the Φ_r term is the Legendre polynomial covariable evaluated at the corresponding THI or Tmax or Tave value standardized in the interval [-1, 1]. Finally, R program was used to derive slope values every five degrees centigrade for the relations between selected climatic variables and dairy traits, using the regression coefficient of cubic polynomial model to study the relation along the range of values of the climatic variable. All analysis were again made independently for each data set formerly described.

2. 4. Results and Discussion

All fixed factors included in the preliminary analyses carried out with GLM procedure were significant for all traits studied. Results of ridge regression and GLM select analyses of the phenotypic response to heat stress for total data set (Table 2.4), warm (HS) and cold (CS) seasons (Table 2.5) and high (HP) and low (LP) productive animals (Table 2.6) gave different values of the regression coefficients between climatic and dairy traits. However, the sign and the ranking of the coefficients for the different dates of recording of climatic variables (the same day, one day and two days before test day) were the same for most traits and climatic variables in both ridge regression and GLM select analyses.

Results of the three GLM select models (THI, average and maximum temperature) show that THI never had the best fitting, while the average or the maximum temperature always had a better fit for all dairy traits in all data bases. Which means that, as oppose to what has been reported in other works (Dikmen and Hansen, 2009), THI index is not the best climatic indicator to explain the change in dairy traits caused by the climatic effect. This result could be explained by the pattern of variation through the year of temperature and humidity in the region where the animals of this breed are raised. Summer in this region, when heat stress is stronger, is characterized by very high temperatures with low humidity (Figure 2.1) and for that combination of temperature and humidity THI values are not very high (Table 2.1).

Table 2. 4. Regression coefficients, obtained with a ridge regression and with GLM select (within parenthesis), between climatic variables (THI, average (Tave) and maximum (Tmax) temperatures), registered at test day (0), one day (1) and two days before (2), and dairy traits recorded to all Florida goats.

	Milk yield (g)			Fat content (%)			Protein content (%)		
	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}
0	93.33 (16.16)	105.72 (15.39)	110.51 (13.49)	-0.32 (-0.05)	-0.40 (-0.06)	-0.35 (-0.04)	-0.06 (-0.011)	-0.12 (-0.017)	-0.06 (-0.008)
1	-50.45 (-7.47)	-84.21 (-12.57)	-73.03 (-7.53)	0.11 (0.02)	0.15 (0.02)	0.13 (0.02)	-0.05 (-0.008)	-0.02 (0.003)	-0.04 (-0.005)
2	8.98	26.03 (3.85)	14.51	-0.07 (-0.01)	-0.03 (-0.004)	-0.07 (-0.01)	-0.02 (-0.003)	-0.03 (-0.005)	-0.03 (-0.003)
SBC	1375643	1375712	1375621	57755	57506	57451	-102258	-102379	-102410
	Fat+Protein yield (g)			**Fat yield (g)**			**Protein yield (g)**		
	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}
0	-0.59	-3.06 (-0.68)	-0.02	-1.80 (-0.35)	-3.68 (-0.51)	-1.51 (-0.22)	1.57 (0.27)	0.75 (0.12)	2.05 (0.25)
1	-2.64 (-0.54)	-2.16	-3.08 (-0.39)	-0.39	-0.27	-0.60	-2.58 (-0.46)	-2.32 (-0.30)	-3.10 (-0.39)
2	-1.25 (-0.21)	0.40	-1.56 (-0.17)	-1.11 (-0.21)	0.38	-1.35 (-0.19)	-0.12	0.30	-0.13
SBC*	860166	860081	860128	770901	770764	770851	692474	692477	692449

* SBC: Schwarz's Bayesian criterion (fitting criteria for the GLM select).

We can see that results obtained for milk yield with both methods (ridge regression and GLM select) are very different and that the magnitude, and even the sign, change depending on the day of recording of climatic variables that is considered. That is not the case for the other traits, for which the differences between the coefficients obtained with both methods are more similar and there are not such a large differences between the values for the different days.

If attention is placed on the coefficients obtained with GLM select for the climatic variable which gives the best fit registered the test day (0), a positive slope of 13.49 g of milk per °C of maximum temperature is observed. Components yields and contents, however, show a negative tendency. This means that, within the range of temperatures registered in the area where these goats are raised, heat stress affect negatively milk components yields and contents and it does not affect milk yield.

In order to see if there are different effects of low and high temperatures, data from the cooler and warmer months were analyzed separately. Results are shown in Table 2.5.

Table 2. 5. Regression coefficients, obtained with a ridge regression and with GLM select (within parenthesis), between climatic variables (THI, average (Tave) and maximum (Tmax) temperatures), registered at test day (0), one day (1) and two days before (2), and dairy traits recorded to warm (HS) and cold (CS) seasons.

	Milk yield (g)						Fat + Protein yield (g)					
	HS			CS			HS			CS		
	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}
0	95.13 (24.45)	161.11 (31.80)	123.08 (19.76)	36.31 (8.35)	-6.98	31.31 (7.27)	0.81	0.33	1.35 (0.26)	1.80	-0.13	2.19 (0.48)
1	-67.64 (-16.01)	-181.38 (-35.48)	-110.33 (-17.96)	-12.61	28.73 (6.44)	-2.21	-2.13 (-0.29)	-4.09 (-0.77)	-2.76 (-0.51)	-1.30	-0.18	-1.30 (-0.35)
2	4.96	46.65 (8.81)	18.73 (2.98)	10.00	6.86	7.91	0.30	1.93 (0.40)	-0.10	-0.14	0.52	-0.36
SBC	720444	720372	720406	654321	654335	654312	444016	443984	444004	414006	414006	414016

	Fat (%)						Protein (%)					
	HS			CS			HS			CS		
	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}
0	-0.29 (-0.07)	-0.46 (-0.09)	-0.35 (-0.06)	-0.04	0.06 (0.02)	0.00	-0.04 (-0.01)	-0.07 (-0.01)	-0.06 (-0.01)	0.02 (0.004)	0.00	0.03 (0.006)
1	0.14 (0.04)	0.34 (0.06)	0.22 (0.03)	0.04	-0.11 (-0.03)	-0.01	-0.01 (-0.003)	0.03	0.01 (-0.002)	-0.04 (-0.009)	-0.01 (-0.003)	-0.06 (-0.01)
2	0.03 (0.01)	-0.02	-0.02	-0.06 (-0.01)	-0.01	-0.05 (-0.01)	-0.01	-0.01	-0.02	0.01	0.00	0.01 (0.002)
SBC	20597	20168	20351	34569	34546	34552	-57200	-57279	-57274	-46451	-46415	-46461

	Fat yield (g)						Protein yield (g)					
	HS			CS			HS			CS		
	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}
0	-0.93 (-0.23)	-2.35 (-0.49)	-0.91 (-0.19)	0.62	0.10	1.08	2.20 (0.57)	3.53 (0.70)	2.60 (0.43)	1.42 (0.39)	-0.33	1.51 (0.34)
1	-0.08	0.04	-0.07	-0.14	-0.69	-0.37	-2.47 (-0.58)	-5.16 (-1.01)	-3.00 (-0.47)	-1.31 (-0.26)	0.52	-1.25 (-0.20)
2	0.15	0.84 (0.19)	-0.28	-0.47	0.44	-0.66	0.17	1.27 (0.24)	0.15	0.44	0.28 0.10	0.45
SBC	396539	396481	396519	372109	372109	372109	356659	356604	356634	334147	334160	334142

* SBC: Schwarz's Bayesian criterion (fitting criteria for the GLM select).

Models with average temperature are the best fitted for most dairy traits studied. This is in agreement with results obtained by Igono *et al.* (1992) who stated that the severity of heat stress depends to the diurnal fluctuations of the ambient temperature, as they found that when the temperature drops at night below 21°C during 3 to 6 hours, animals have sufficient opportunity to lose all heat accumulated on previous day.

The pattern of values obtained for the HS data set with both analytical methods and the rankings and signs of coefficients estimated for the climatic values recorded on different dates are similar to those in Table 2.4, obtained with the complete set of data. However, the ranking and signs of the estimates of these slopes obtained when the CS was analyzed are different. This means that the responses of these traits to the variation of average temperatures are different for the cold season than for the warm season.

The effect of climate might vary from high yielding to low yielding animals. The first are expected to be more sensitive (Berman, 2005). Therefore, independent analyses were carried with the data from these two types of goats. Results are shown in Table 2.6. The best fitted models for high productive animals are those with maximum temperature for milk yield and average temperature for all yields and contents of milk components. The pattern of relationships between the regression coefficients, and the ranking of values corresponding to different dates of recording of the climatic variables, obtained with the ridge regression method are more or less similar in both sets of data. However, for low productive animals, it appears that different climatic variables have no significant effect on fat, protein and fat plus protein yields, as no climatic variable was selected with the GLM select procedure in any of the three models (THI, average and maximum temperature).

Results of linear regression analysis for the climatic variables in the selected models for each dairy tested trait are shown in Table 2.7 for total, high and low productive animals and in Table 2.8 for warm and cold seasons. R-square values for all analyzed variables were generally low. The estimated coefficient of climatic variables obtained for total, high and low productive animals (Table 2.7) and warm and cold seasons (Table 2.8) show that there is a negative effect on fat and protein percentage, fat, protein and fat plus protein yield. That is not the case with the estimated coefficient for climatic variables (Tmax0 and Tmax1) on protein yield for cold season data. On the other hand, the estimated coefficients of climatic variables for the complete data set show a positive effect on daily milk yield.

Table 2. 6. Regression coefficients, obtained with a ridge regression and with GLM select (within parenthesis), between climatic variables (THI, average (Tave) and maximum (Tmax) temperatures), registered at test day (0), one day (1) and two days before (2), and dairy traits recorded to high (HP) and low (LP) productive animals.

	Milk yield (g)						Fat + Protein yield (g)					
	HP			LP			HP			LP		
	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}
0	21.94 (5.62)	74.23 (13.44)	40.66 (4.39)	27.84 (13.27)	30.85 (11.07)	33.51 (9.25)	-3.33 (-0.74)	-3.29	-2.57 (-0.43)	-0.25	-1.13	-0.13
1	25.24	-29.37 (-9.74)	5.43	21.15	14.73	15.79	-1.82	-2.91 (-1.26)	-2.13	-0.38	-1.20	-0.70
2	-14.75	-19.37	-12.22	26.91	30.19	25.21	-3.24 (-0.67)	-2.70	-3.71 (-0.59)	0.61	2.11	0.51
SBC	312645	312654	312640	46825	46825	46825	196726	196684	196723	29079	29079	29079
	Fat (%)						Protein (%)					
	HP			LP			HP			LP		
	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}
0	-0.17 (-0.03)	-0.31 (-0.04)	-0.21 (-0.03)	-0.24 (-0.05)	-0.28 (-0.04)	-0.36 (-0.04)	-0.07 (-0.014)	-0.09 (-0.015)	-0.07 (-0.01)	-0.08 (-0.02)	-0.18 (-0.02)	-0.08 (-0.016)
1	-0.06	0.06	-0.02	0.001	-0.01	0.11	-0.04	-0.02	-0.04	-0.03	0.10	-0.03
2	-0.04 (-0.01)	-0.02	-0.05 (-0.01)	-0.06	-0.01	-0.07	-0.02 (-0.007)	-0.02 (-0.003)	-0.03 (-0.005)	-0.03	-0.06	-0.04
SBC	11237	11153	11174	2108	2097	2094	-23861	-23890	-23887	-3250	-3259	-3253
	Fat yield (g)						Protein yield (g)					
	HP			LP			HP			LP		
	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}	THI	T_{ave}	T_{max}
0	-2.50 (-0.58)	-3.29 (-0.87)	-2.25 (-0.37)	-0.78	-2.24	-0.68	-1.06 (-0.22)	-0.36	-0.37	-0.06	-0.23	0.05
1	-1.37	-1.53	-1.33	0.16	-0.41	-0.16	-0.39	-1.34 (-0.38)	-0.82	-0.20	-0.22	-0.33
2	-1.88 (-0.39)	-1.29	-2.22 (-0.34)	0.41	2.27	0.31	-1.01 (-0.19)	-0.96	-1.23 (-0.28)	0.17	0.33	0.10
SBC	177297	177245	177290	25905	25905	25905	160099	160067	160092	23107	23107	23107

* SBC: Schwarz's Bayesian criterion (fitting criteria for the GLM select).

Table 2. 7. Regression (slope) and determination (R^2) coefficients of linear regressions between climatic variables (var.) best fitted in previous analyses and dairy traits for total (TP), high (HP) and low (LP) productive Florida goats.

	TP			HP			LP		
	Var.	Slope	R^2	Var.	Slope	R^2	Var.	Slope	R^2
Milk	T_{max0}	6.45	0.291	T_{max0}	4.39	0.279	THI_0	13.27	0.35
	T_{max1}	5.49	0.290				T_{ave0}	11.07	0.36
							T_{max0}	9.25	0.35
Fat (g)	T_{ave0}	-0.51	0.193	T_{ave0}	-0.87	0.159	---		
Protein (g)	T_{max0}	-0.12	0.180	T_{ave1}	-0.38	0.141	---		
	T_{max1}	-0.15	0.181						
Fat+Protein (g)	T_{ave0}	-0.68	0.291	T_{ave1}	-1.26	0.268	---		
Fat (%)	T_{max0}	-0.03	0.225	T_{ave0}	-0.04	0.213	T_{max0}	-0.05	0.33
	T_{max1}	-0.03	0.217						
	T_{max2}	-0.03	0.215						
Protein (%)	T_{max0}	-0.01	0.195	T_{ave0}	-0.02	0.213	T_{ave0}	-0.02	0.28
	T_{max1}	-0.01	0.196	T_{ave2}	-0.02	0.207			
	T_{max2}	-0.01	0.190						

T_{max0}, T_{max1},T_{max2}: maximum temperature day of control, one and two days before.
T_{ave0}, T_{ave1},T_{ave2}: average temperature day of control, one and two days before.
THI_0: temperature humidity index day of control.

Table 2. 8. Regression (slope) and determination (R^2) coefficients of linear regressions between climatic variables (var.) best fitted in previous analyses and dairy traits for warm season (HS) and cold season (CS) data sets of Florida goats.

	HS			CS		
	Var.	Slope	R^2	Var.	Slope	R^2
Milk	T_{ave0}	6.08	0.323	T_{max0}	7.27	0.288
	T_{ave1}	2.43	0.322			
	T_{ave2}	2.76	0.322			
Fat (g)	T_{ave0}	-0.33	0.194	---		
	T_{ave2}	-0.21	0.193			
Protein (g)	T_{ave0}	-0.04	0.194	T_{max0}	0.16	0.170
	T_{ave1}	-0.13	0.195	T_{max1}	0.08	0.169
	T_{ave2}	-0.10	0.194			
Fat+Protein (g)	T_{ave1}	-0.40	0.302	---		
	T_{ave2}	-0.30	0.301			
Fat (%)	T_{ave0}	-0.03	0.215	T_{ave0}	-0.01	0.203
	T_{ave1}	-0.02	0.205	T_{ave1}	-0.013	0.205
Protein (%)	T_{ave0}	-0.01	0.176	T_{max0}	-0.004	0.189
				T_{max1}	-0.006	0.191
				T_{max2}	-0.004	0.189

T_{max0}, T_{max1}, T_{max2}: maximum temperature day of control, one and two days before.
T_{ave0}, T_{ave1}, T_{ave2}: average temperature day of control, one and two days before.

The climatic variable most correlated to each dairy trait was determined according to the R-square values. It is clear that high productive animals are more affected by climatic variables as they have a lower positive coefficient of regression on milk yield while they have a higher negative value for all milk composition traits (Table 2.7). All coefficients of determination are very low, which indicates that simple linear regression models do not explain well the relations between climatic variables and dairy traits. The largest effect is found for milk yield and, particularly, in low yielding goats. Effects are positive on milk yield and negative on the rest of the dairy traits studied.

An analysis to estimate the tolerance threshold and slope of the effect of the previously selected climatic variables on productive traits by means of a Bayesian procedure was carried out. Table 2.9 presents the results of mean tolerance threshold and slope of selected climatic variables on daily milk yield for all (TP), high (HP) and low (LP) productive animals, warm (HS) and cold (CS) seasons.

Table 2. 9. Mean tolerance threshold (knot) and slope selected of climatic variables on daily milk yield for Total (TP), high (HP) and low (LP) productive animals, warm (HS) and cold (CS) seasons.

		Milk (kg)				
Data set		TP	HP	LP	HS	CS
Selected climatic variable		T_{max0}	T_{max0}	T_{ave0}	T_{ave0}	T_{max0}
Knot	mean	6.79	26.34	33.32	29.99	20.49
	SD	1.77	2.23	0.80	0.07	1.04
	MC Error	0.24	0.29	0.05	0.003	0.14
	HD95	3.03 9.22	19.96 28.96	31.64 34.99	29.85 30.13	17.78 21.53
Slope	mean	0.010	0.02	-0.508	0.098	0.025
	SD	0.0004	0.004	19.12	0.01	0.004
	MC Error	0.000005	0.0003	0.84	0.0002	0.0004
	HD95	0.009 0.011	0.012 0.026	-18.87 0.53	0.08 0.12	0.017 0.031
Var_a	mean	0.276	0.268	0.173	0.251	0.267
	SD	0.005	0.014	0.019	0.005	0.007
	MC Error	0.0001	0.0003	0.0005	0.0001	0.0002
	HD95	0.266 0.286	0.242 0.295	0.138 0.213	0.240 0.261	0.254 0.280
Var_e	mean	0.585	0.835	0.473	0.481	0.677
	SD	0.003	0.008	0.012	0.003	0.005
	MC Error	0.00004	0.0001	0.0002	0.00005	0.00007
	HD95	0.580 0.590	0.818 0.851	0.449 0.496	0.475 0.488	0.667 0.686

T_{max0}: maximum temperature day of control.
T_{ave0}: average temperature day of control.
Var a: Animal (permanent environmental) variance.
SD: standard deviation.
MC Error: Monte Carlo Error.
HD95: high posterior density intervals (95%)
Var e: Residual variance.

The relation between climatic variables and daily milk yield had positive slopes for all, high productive animals, warm and cold seasons, while it had a negative slope for low productive animal. This negative slope of average temperature at test day on daily milk yield in low productive animals starts at very high temperature (33.32° C). Furthermore, this slope has a very high standard deviation range, which means that it is not significantly different from zero. The highest positive slope of the climatic variables on daily milk yield was recorded for warm season data (98 g/day for each Celsius degree), which could possibly a consequence of a higher water consumption as Shafie *et al.* (1994) determined a double water consumption during heat stress. The threshold values obtained in the analyses with the complete data set were very low (6.79° C).

Results show a negative influence (slope) of climatic variables on daily fat yield for total, high productive animals and warm season data (Table 2.10).

Table 2. 10. Mean tolerance threshold (knot) and slope of selected climatic variables on daily fat yield for total (TP), high (HP) and low (LP) productive animals, warm (HS) and cold (CS) seasons.

		Fat (g)				
Data set		TP	HP	LP	HS	CS
Selected climatic variable		T_{ave0}	T_{ave0}	----	T_{ave0}	---
Knot	mean	32.00	9.24		32.01	
	SD	0.62	1.28		0.65	
	MC Error	0.06	0.13		0.08	
	HD95	30.93 33.10	6.98 12.57		30.92 33.15	
Slope	mean	-12.42	-0.84		-11.71	
	SD	4.70	0.08		4.67	
	MC Error	0.48	0.003		0.56	
	HD95	-22.54 -5.93	-0.99 -0.70		-21.99 -5.63	
Var_a	mean	452.56	428.81		369.03	
	SD	10.18	26.09		11.05	
	MC Error	0.25	0.66		0.39	
	HD95	433.5 473.1	377.6 480.1		348.5 392.0	
Var_e	mean	2137.96	3046.55		1705.72	
	SD	9.90	30.37		11.57	
	MC Error	0.14	0.40		0.19	
	HD95	2119 2157	2987 3107		1682 1728	

T_{ave0}: average temperature day of control.
HD95: high posterior density intervals (95%)
Var_e: Residual variance.
MC Error: Monte Carlo Error
Var_a: Animal (permanent environmental) variance
SD: standard deviation.

Slopes for daily fat yield and average temperature at test day, obtained with the complete and warm season data set, were very similar (-12.42 and -11.71 g/day increase per °C, respectively). Likewise, tolerance threshold for total and warm season data were almost the same (32.00 and 32.01° C).

On the contrary, the slope estimated for this trait in high productive animals was very small compared with the value from the complete data set (-0.84 vs. -12.42 g/day) and tolerance threshold occurred at a lower temperature (9.24 vs. 32.00 °C). Slope values indicate that high yielding animals are less sensitive to heat stress in respect to this trait, which is not in agreement with what could be expected and with the results reported for Manchega sheep (Carabaño *et al.*, 2013). These authors found that in this breed of sheep high yielding animals had higher slope of regressions of maximum and average temperature on daily fat yield. Our result is also difficult to explain because this difference is not observed for milk yield (Table 2.9) and fat content (Table 2.13). Besides, the response to heat stress (threshold) of this trait in HP goats started much earlier, indicating what could be expected, a higher sensitivity of this animals.

For daily protein yield, mean tolerance threshold and slope of selected climatic variables for total, high productive animals, warm and cold seasons are shown in Table 2.11. The analyses of the whole and the high productive animals data sets gave negative slopes of maximum and average temperature, respectively, registered one day before control day. The slope for high productive animal was higher than the slope for total data set (-0.66 vs. -0.15, respectively), which is what could be expected, but their tolerance threshold occurred at a higher temperature (20.49 vs. 8.86, respectively). Similar results were found by Carabaño *et al.* (2013), as they reported a higher slope of THI index on daily protein yield for high productive sheep, with a tolerance threshold occurring also at higher THI value. On the other hand, the slope for warm and cold seasons data were both positive but higher for cold season data (5.62), which means that protein yield increases more when passing from cold to moderate temperatures than when temperature changes from moderate to high values. Moreover, the slope for worm season data has a very high standard deviation range.

Table 2. 11. Mean tolerance threshold (knot) and slope of selected climatic variables on daily protein yield for total (TP), high (HP) and low (LP) productive animals, warm (HS) and cold (CS) seasons.

		Protein (g)				
Data set		TP	HP	LP	HS	CS
Selected climatic variable		T_{max1}	T_{ave1}	----	T_{ave1}	T_{max0}
Knot	mean	8.86	20.49		26.05	30.22
	SD	4.15	1.15		3.76	0.64
	MC Error	0.55	0.08		0.47	0.03
	HD95	0.41 13.65	18.13 22.41		20.49 31.85	29.01 31.47
Slope	mean	-0.15	-0.66		0.61	5.62
	SD	0.02	0.14		13.42	1.64
	MC Error	0.0004	0.006		1.02	0.07
	HD95	-0.19 -0.13	-0.94 -0.41		-3.11 8.90	2.85 9.04
Var_a	mean	193.06	162.65		168.72	196.30
	SD	4.50	10.66		5.10	6.95
	MC Error	0.10	0.29		0.14	0.27
	HD95	184.8 202.3	142.4 184.2		158.6 178.6	182.4 209.7
Var_e	mean	986.55	1493.32		796.80	1183.53
	SD	4.61	14.67		5.47	8.52
	MC Error	0.04	0.19		0.09	0.15
	HD95	977.3 995.2	1465 1522		786.0 807.0	1167 1200

T_{max0}, T_{max1}: maximum temperature day of control and one day before. MC Error: Monte Carlo Error
T_{ave1}: average temperature one day before control day. HD95: high posterior density intervals (95%)
Var_a: Animal (permanent environmental) variance. Var_e: Residual variance.
SD: standard deviation.

Slopes of selected climatic variables on daily fat plus protein yield were negative for all animals (Table 2.12). High productive animals show higher effect (slopes) of heat stress. Therefore, animals with higher production level suffer more the effect of heat stress than total animals. The slope is also higher when estimated with data collected during the warm season, as it was expected. Threshold values are, however, similar for all animals and for high productive animals, but the threshold estimated with warm season data set is higher. It is not possible to do comparisons with the result obtained with data registered during the cold season, since the GLM select procedure did not select any climatic variable registered during this season. However, if we compare the threshold and the slope estimated with all data and those estimated with warm season data, it can be observed that they show different responses to heat stress. This is what would be expected when looking at the graphic representation of the change of fat plus protein yield through the scale of temperatures (Figure 2.5 a).

Table 2. 12. Mean tolerance threshold (knot) and slope of selected climatic variables on daily fat plus protein yield for total (TP), high (HP) and low (LP) productive animals, warm (HS) and cold (CS) seasons.

		Fat + Protein (g)				
Data set		TP	HP	LP	HS	CS
Selected climatic variable		T_{ave0}	T_{ave1}	----	T_{ave1}	----
Knot	mean	8.61	9.25		20.61	
	SD	0.42	1.20		0.47	
	MC Error	0.02	0.01		0.03	
	HD95	7.81 9.34	6.59 11.20		19.63 21.44	
Slope	mean	-0.78	-1.13		-1.25	
	SD	0.03	0.09		0.10	
	MC Error	0.0004	0.003		0.004	
	HD95	-0.85 -0.71	-1.32 -0.95		-1.45 -1.06	
Var_a	mean	1596.6	1519.6		1355.4	
	SD	29.92	73.73		29.73	
	MC Error	0.54	1.65		0.62	
	HD95	1536 1651	1377 1665		1296 1413	
Var_e	mean	3326.82	4460.23		2530.86	
	SD	15.86	43.47		17.24	
	MC Error	0.24	0.46		0.24	
	HD95	3297 3359	44374 4545		2498 2565	

T_{ave0}, T_{ave1}: average temperature day of control and one day before. MC Error: Monte Carlo Error.
HD95: high posterior density intervals (95%). Var_a: Animal (permanent environmental) variance.
Var_e: Residual variance. SD: standard deviation.

Table 2.13 shows the results of mean tolerance threshold and slope of selected climatic variables on fat percentage for all, high and low productive animals, as well as on warm and cold seasons data. Climatic variables had a negative influence on fat content in all data set. Slope values were low and similar for all, high and low productive animals (about -0.05) with not very high tolerance threshold in all cases (16.92, 8.36 and 5.23° C, for all, high and low productive animals, respectively). It seems, therefore, that production level makes no difference with respect to the effect of temperature on fat content. This is similar to what was reported for the same breed when comparing the effects of maximum and average temperature on fat content on all and on high productive animals (Carabaño *et* *al.*, 2013). A higher effect of temperature was observed when data registered during warm and cold seasons were analyzed (-0.31 and -0.57, respectively) with higher tolerance thresholds (29.83 and 25.48° C, respectively). This difference with respect to the results obtained with all data is to be expected when looking at the change of fat contents along the range of temperatures (Figure 2.6 a). Different types of responses are observed, with higher slope of lines corresponding to warm and cold seasons data sets. On the other hand, it is difficult to explain why different threshold were estimated with the different data sets, since not an apparently threshold can be seen in the figures in any case.

Table 2. 13. Mean tolerance threshold (knot) and slope of selected climatic variables on daily fat percentage for total (TP), high (HP) and low (LP) productive animals, warm (HS) and cold (CS) seasons.

		Fat (%)				
Data set		TP	HP	LP	HS	CS
Selected climatic variable		T_{max0}	T_{ave0}	T_{max0}	T_{ave0}	T_{ave1}
Knot	mean	16.92	8.36	5.23	29.83	25.48
	SD	0.12	0.79	2.84	0.09	0.54
	MC Error	0.008	0.10	0.42	0.006	0.07
	HD95	16.66 17.14	6.55 9.39	0.09 10.01	29.65 29.96	24.95 26.79
Slope	mean	-0.05	-0.055	-0.05	-0.31	-0.57
	SD	0.0006	0.002	0.003	0.02	0.20
	MC Error	0.00002	0.00007	0.00003	0.0007	0.03
	HD95	-0.053 -0.051	-0.058 0.052	-0.052 -0.042	-0.34 -0.28	-1.07 -0.38
Var_a	mean	0.18	0.15	0.19	0.15	0.18
	SD	0.005	0.009	0.026	0.005	0.008
	MC Error	0.0001	0.0002	0.0008	0.0002	0.0004
	HD95	0.171 0.189	0.131 0.168	0.134 0.236	0.143 0.165	0.161 0.191
Var_e	mean	1.32	1.24	1.08	1.05	1.54
	SD	0.006	0.01	0.028	0.007	0.01
	MC Error	0.00009	0.0001	0.0004	0.0001	0.0002
	HD95	1.31 1.33	1.22 1.27	1.03 1.14	1.03 1.06	1.51 1.56

T_{max0}: maximum temperature day of control.
T_{ave0}, T_{ave1}: average temperature day of control and one day before. MC Error: Monte Carlo Error
HD95: high posterior density intervals (95%) Var_a: Animal (permanent environmental) variance
Var_e: Residual variance. SD: standard deviation.

For protein percentage, mean tolerance thresholds and slopes of selected climatic variables for data from all, high productive animals, warm and cold seasons are shown in Table 2.14. Negative, but small effects of climatic variables on protein content are observed for all data set. This is in agreement with other works for goats (Carabaño *et al.*, 2013; Menéndez-Buxadera *et al.*, 2012) and sheep (Finocchiaro *et al.*, 2005) where climatic variables were reported to have a lower effect on protein content than on fat content. Cold season data have, particularly, a very low negative slope (-0.009) with a very low tolerance threshold (3.90° C). The highest negative slope was -0.029 for low productive animals with a low tolerance threshold (7.58° C). Although some of the tolerance thresholds estimated with the different data sets can be explained having into account the form of the observed response curves (Figures 2.2 a to 2.7 a), most of the tolerance threshold for all dairy traits were unexpected and difficult to explained, showing rare patterns of relations between them. Therefore, further analyses were carried out with a Bayesian methodology to fit linear (spline) and polynomial models, searching for a better identification of the relations between climatic and dairy variables.

Table 2. 14. Mean tolerance threshold (knot) and slope of selected climatic variables on daily protein percentage for total (TP), high (HP) and low (LP) productive animals, warm (HS) and cold (CS) seasons.

		Protein (%)				
Data set		TP	HP	LP	HS	CS
Selected climatic variable		T_{max1}	T_{ave0}	T_{ave0}	T_{ave0}	T_{max1}
Knot	mean	3.81	5.88	7.58	15.25	3.90
	SD	1.11	0.87	2.21	1.07	1.67
	MC Error	0.14	0.12	2.77	0.14	0.22
	HD95	1.46 6.20	4.24 7.31	2.75 10.31	13.68 17.46	0.21 6.40
Slope	mean	-0.021	-0.024	-0.029	-0.018	-0.009
	SD	0.0002	0.0006	0.001	0.0008	0.0005
	MC Error	0.000003	0.00002	0.00009	0.00008	0.000006
	HD95	-0.021 -0.020	-0.025 -0.023	-0.031 -0.026	-0.020 -0.017	-0.010 -0.008
Var_a	mean	0.057	0.054	0.052	0.051	0.070
	SD	0.001	0.003	0.005	0.001	0.002
	MC Error	0.00003	0.00004	0.0001	0.00005	0.00005
	HD95	0.055 0.060	0.049 0.059	0.042 0.063	0.048 0.054	0.066 0.074
Var_e	mean	0.205	0.192	0.109	0.187	0.200
	SD	0.001	0.002	0.003	0.001	0.001
	MC Error	0.00001	0.00002	0.00004	0.00002	0.00002
	HD95	0.203 0.207	0.189 0.196	0.104 0.115	0.184 0.189	0.197 0.202

T_{max1}: maximum temperature one day before day of control; T_{ave0}: average temperature day of control.
MC Error: Monte Carlo Error; HD95: high posterior density intervals (95%); SD: standard deviation.
Var_a: Animal (permanent environmental) variance; Var_e: Residual variance.

Results obtained with these analyses showed that the cubic polynomial models have almost the same pattern as the quadratic model in explaining the relation between the selected climatic variables and the dairy traits. Slope values derived every five degrees centigrade for the relations between selected climatic variables and milk (Table 2.15), fat (Table 2.17), protein (Table 2.19) and fat plus protein yield (Table 2.21) and fat (Table 2.23) and protein (Table 2.25) contents, were calculated using cubic polynomial model. Coefficients of regression of the cubic Legendre polynomial of the selected climatic variables on milk, fat, protein and fat plus protein yield, fat and protein contents for every data sets are shown in Tables 2.16, 2.18, 2.20, 2.22, 2.24 and 2.26, respectively. Graphic representation of the change of raw, adjusted (corrected for the fixed environmental factors) and estimated (with lineal, quadratic and cubic Legendre polynomial models) values of milk, fat, protein and fat plus protein yield, fat and protein contents, along the range of values of the climatic variable previously selected for each data set, are shown in Figures 2.2, 2.3, 2.4, 2.5, 2.6 and 2.7, respectively.

Daily goat milk production seems to increase when temperature increases in all cases (Table 2.15). Milk production shows a near stable value between 20 and 25° C when data from all, high productive animals and warm season are analyzed, while this stable zone starts at a colder temperature (15° C) for cold season data (Table 2.15 and figure 2.2). For low productive animals there is not a zone of constant yield and the production continuously increase with temperature. A decrease of milk production was only observed for low production animals when temperature exceeds 30° C (Table 2.15 and figure 2.2). The pattern of the increase of milk production did not allow calculating the temperature at which the yield is maximum except for low productive animals (29.81° C, Table 2.15).

Looking at raw and adjusted milk data and comparing them with the values estimated with the polynomial model, we can observed an decrease of production when temperature increase with raw and adjusted data, while with estimated data yields do not decrease except in low productive animal data (figure 2.2).

Baccari Júnior *et al.* (1996) reported that Saanen goats did not show different daily milk yield when exposed to heat stress for 14 days, but daily water intake was significantly higher. Shafie *et al.* (1994) also determined the increase in water intake to be 50% during the heat stress period in sheep. This could explain the reason for milk production not decreasing when temperatures increase. However, no works were found comparing this effect at different levels of production or in different seasons.

Table 2. 15. Derived values of the slopes of the relation between selected climatic variables and milk yield (kg) at different temperatures (ºC) and temperatures at which yield is maximum, obtained by cubic polynomial models for total (TP), high (HP) and low (LP) productive animals, warm (HS) and cold (CS) seasons.

Milk (kg)	TP	HP	LP	HS	CS
	T_{max0}	T_{max0}	T_{ave0}	T_{ave0}	T_{max0}
Maximum	---	---	29.81	---	---
Derived					
5	0.594	0.645	0.027	---	0.951
10	0.354	0.335	0.110	0.573	0.319
15	0.178	0.122	0.140	0.184	-0.029
20	0.066	0.007	0.118	-0.014	-0.009
25	0.018	-0.012	0.043	-0.022	0.126
30	0.034	0.065	-0.084	0.161	0.630
35	0.114	0.240	---	0.535	1.418
40	0.259	0.512	---	---	---

T_{max0}: maximum temperature day of control, T_{ave0}: average temperature day of control.

This result is compatible with the thought that goats are more resistant and adaptable specie to climatic extremes, especially to high ambient temperatures (Sevi and Caroprese, 2012; Oseni and Bebe, 2010). In dairy cattle it has been demonstrated that milk production is affected by heat stress when THI values are higher than 72, which corresponds to 22 °C at 100 % humidity, 25 °C at 50 % humidity, or 28 °C at 20 % humidity (Du Preez *et al.*, 1990) and the production decline was estimated to be 0.2 kg per unit increase in THI when THI exceeded 72 (Ravagnolo *et al.*, 2000). This same rate is observed in the case of Florida goats, but with a positive sign, reflecting that milk yield of these goats is more sensitive to cold than to warm temperatures, which coincide with farmer’s experience.

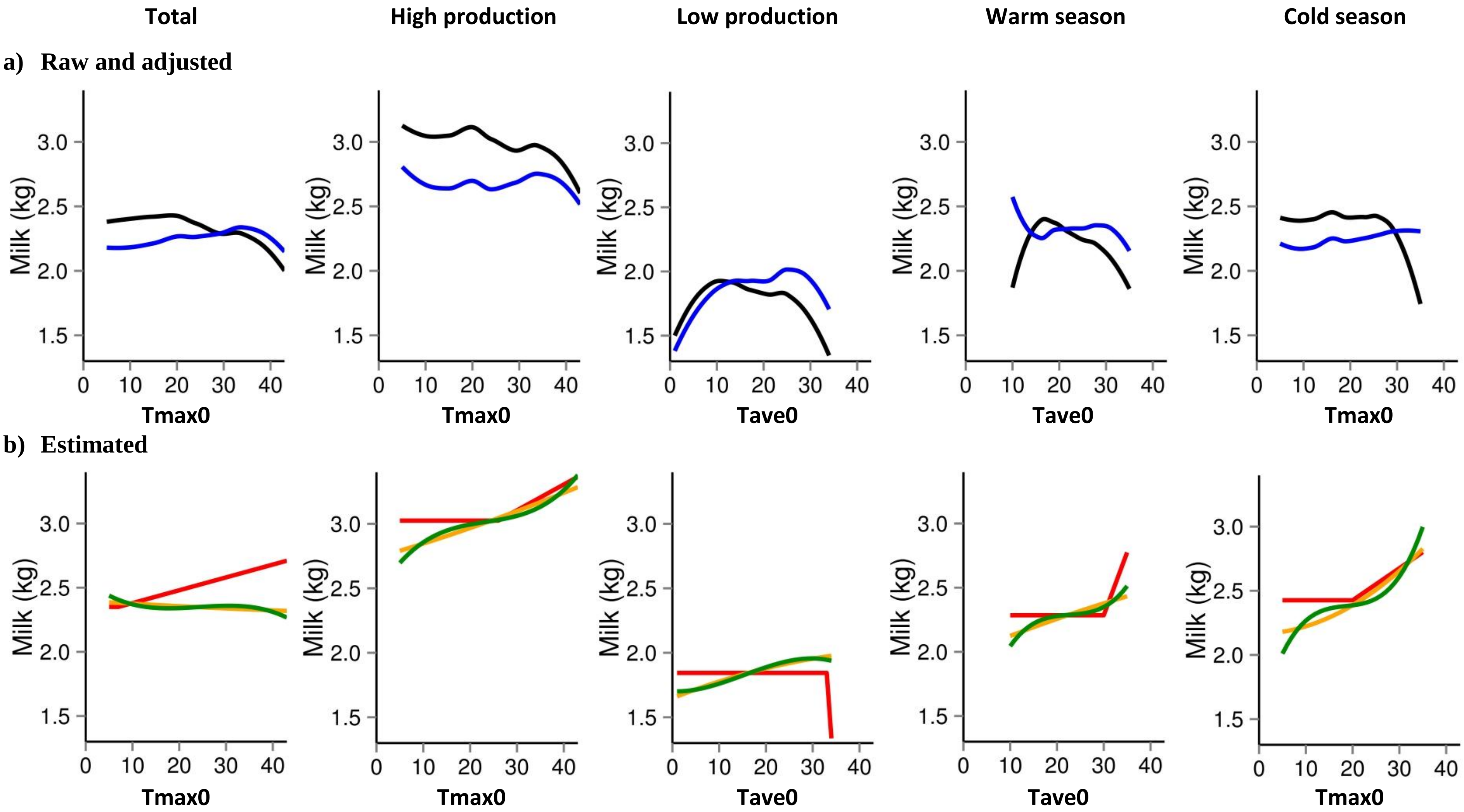


Figure 2. 2. a) Plots of raw (black line) and adjusted (blue line) milk yield (kg) *vs.* climatic variables. b) Estimated effects of climatic variables on milk yield using splines (red line) and quadratic (orange line) and cubic (green line) Legendre polynomials.

Table 2. 16. Posterior means, standard deviations (SD), Monte Carlo (MC) error and 95% high posterior density (HD95) intervals of the regression coefficients, animal and residual variances obtained with Legendre polynomial models of the relation of the selected climatic variables with daily milk yield.

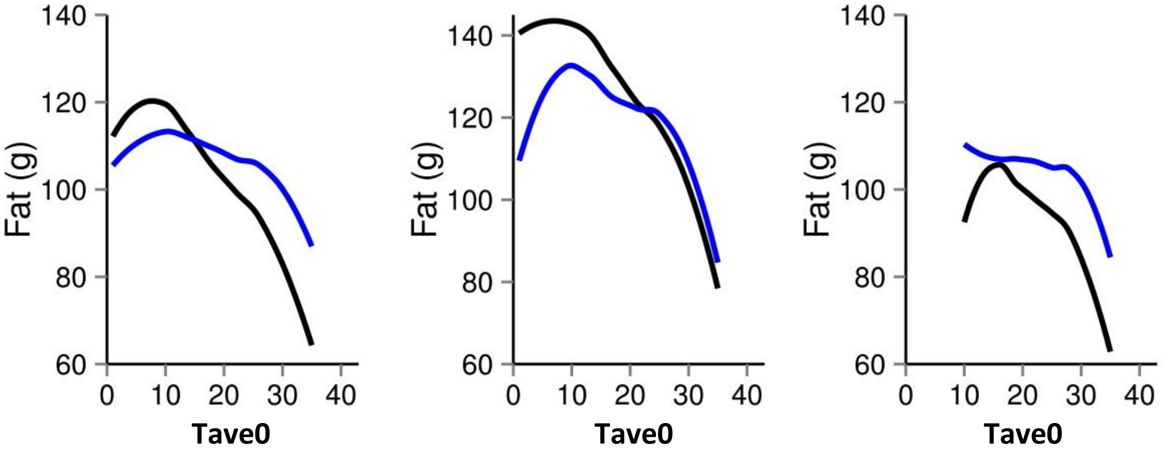
Milk (kg)		TP	HP	LP	HS	CS
		T_{max0}	T_{max0}	T_{ave0}	T_{ave0}	T_{max0}
Coef1	mean	0.230	0.247	0.157	0.155	0.324
	SD	0.009	0.023	0.049	0.013	0.024
	MC Error	0.00009	0.0003	0.0006	0.0002	0.0002
	HD95	0.211 0.248	0.203 0.293	0.061 0.254	0.129 0.179	0.278 0.370
Coef 2	mean	-0.036	0.013	-0.025	-0.006	0.078
	SD	0.009	0.024	0.046	0.013	0.022
	MC Error	0.0001	0.0003	0.0006	0.0002	0.0002
	HD95	-0.054 -0.018	-0.033 0.058	-0.115 0.065	-0.033 0.018	0.035 0.122
Coef 3	mean	0.062	0.093	-0.038	0.079	0.170
	SD	0.012	0.029	0.060	0.016	0.024
	MC Error	0.0001	0.0004	0.0007	0.0002	0.0002
	HD95	0.038 0.084	0.038 0.151	-0.158 0.077	0.048 0.111	0.123 0.218
Var_a	mean	0.276	0.267	0.175	0.252	0.268
	SD	0.005	0.013	0.019	0.006	0.006
	MC Error	0.0001	0.0002	0.0005	0.0001	0.0001
	HD95	0.266 0.286	0.243 0.294	0.141 0.216	0.241 0.263	0.256 0.281
Var_e	mean	0.585	0.834	0.469	0.480	0.675
	SD	0.003	0.008	0.012	0.003	0.005
	MC Error	0.00003	0.0001	0.0002	0.00005	0.00006
	HD95	0.579 0.590	0.819 0.851	0.445 0.493	0.474 0.487	0.666 0.685

TP: total data, HP: high productive animals, LP: low productive animals, HS: warm season, CS: cold season.
T_{max0}: maximum temperature day of control, T_{ave0}: average temperature day of control.
Coef 1; Coef 2; Coef 3: coefficients of regression of first, second and third Legendre polynomial.
Var_a: Animal (permanent environmental) variance; Var_e: Residual variance.

By analyzing fat yield data, we found that daily production increase with increase of temperature till about 13° C, then start to decrease for both the whole set and the set of high productive animals but with a higher slope value for the high productive animals (Table 2.17 and figure 2.3). Carabaño *et al.* (2013) also found that average temperature have higher slope value on high productive sheep than on total population. However, for warm season data this pattern of increase production up to 13° C can’t be seen, as the lower temperature is 10° C and decreasing in production occurred later than for all and high productive animals. Decrease in fat production for warm season data had lower slope than for all and high productive animals up to 25°C, then the ranking of slopes shift, meaning that fat yield of high producing animals is more sensitive to heat stress above this temperature. Temperature of maximum fat production was 8.09 and 9.21°C for total and high productive animals, respectively, while it was a little higher (12.97°C) for warm season data (Table 2.17). Generally, warm season data had a low average production than total and high productive animals (figure 2.3), reflecting the effect of heat stress on fat yield.

Total **High production** **Warm season**

a) Raw and adjusted



b) Estimated

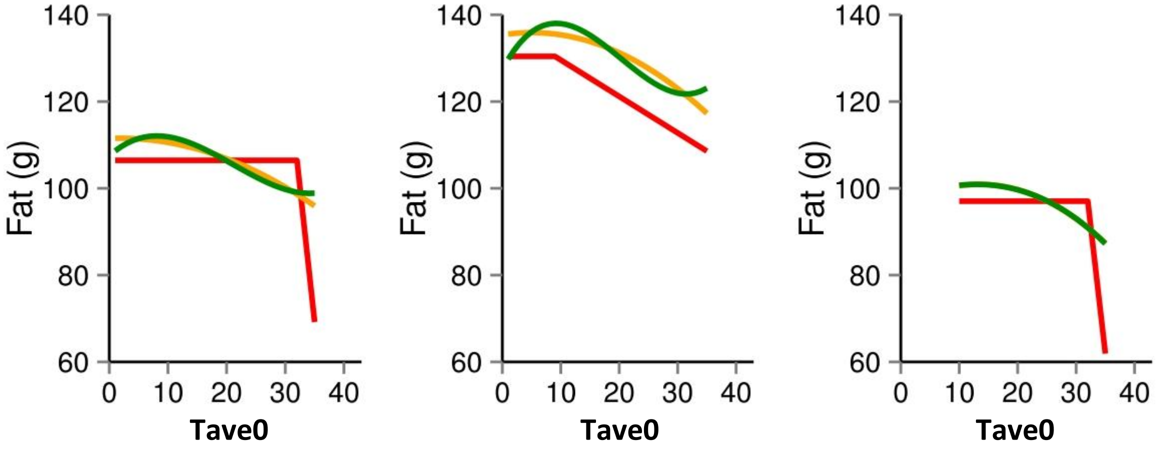


Figure 2. 3. a) Plots of raw (black line) and adjusted (blue line) fat yield *vs.* climatic variables. b) Estimated effects of climatic variables on fat yield using splines (red line) and quadratic (orange line) and cubic (green line) Legendre polynomials.

Table 2. 17. Derived values of the slopes of the relation between selected climatic variables and daily fat yield (g) at different temperatures (ºC) , and temperatures at which the production is maximum, obtained by cubic polynomial models for total (TP), high (HP) and low (LP) productive animals, warm (HS) and cold (CS) seasons.

Fat (g)		TP	HP	LP	HS	CS
		T_{ave0}	T_{ave0}	----	T_{ave0}	---
Maximum		8.09	9.21		12.97	
Derived	5	10.75	21.32		---	
	10	0.39	2.00		5.00	
	15	-6.17	-9.79		2.05	
	20	-8.94	-14.07		-1.27	
	25	-7.90	-10.82		-4.95	
	30	-3.07	-0.06		-8.99	
	35	5.56	18.22		-13.39	

T_{ave0}: average temperature day of control.

Table 2. 18. Posterior means, stander deviation (SD), Monte Carlo (MC) error and 95% high posterior density (HD95) intervals of the regression coefficients, animal and residual variances in the Legendre polynomial models for daily fat yield.

Fat (g)		TP	HP	LP	HS	CS
		T_{ave0}	T_{ave0}	----	T_{ave0}	---
Coef1	mean	-8.79	-9.13		-6.58	
	SD	0.67	1.63		0.76	
	MC Error	0.008	0.018		0.008	
	HD95	-9.08 -6.42	-12.18 -5.93		-8.09 -5.11	
Coef 2	mean	-2.71	-3.99		-3.06	
	SD	0.61	1.55		0.77	
	MC Error	0.008	0.017		0.008	
	HD95	-3.91 -1.54	-6.97 -0.96		-4.57 -1.54	
Coef 3	mean	2.93	5.79		-0.15	
	SD	0.78	1.92		0.96	
	MC Error	0.01	0.026		0.001	
	HD95	1.32 4.41	2.15 9.62		-2.05 1.72	
Var_a	mean	0.44	0.43		0.37	
	SD	0.01	0.026		0.01	
	MC Error	0.0003	0.0006		0.0003	
	HD95	0.423 0.464	0.38 0.48		0.346 0.390	
Var_e	mean	2.13	3.05		1.70	
	SD	0.01	0.03		0.01	
	MC Error	0.0002	0.0004		0.0002	
	HD95	2.11 0.215	2.99 3.11		1.68 1.73	

TP: total data, HP: high productive animals, LP: low productive animals, HS: warm season, CS: cold season. T_{ave0}: average temperature day of control. Coef 1; Coef 2; Coef 3: coefficients of regression of first, second and third Legendre polynomial; Var_a: Animal (permanent environmental) variance; Var_e: Residual variance.

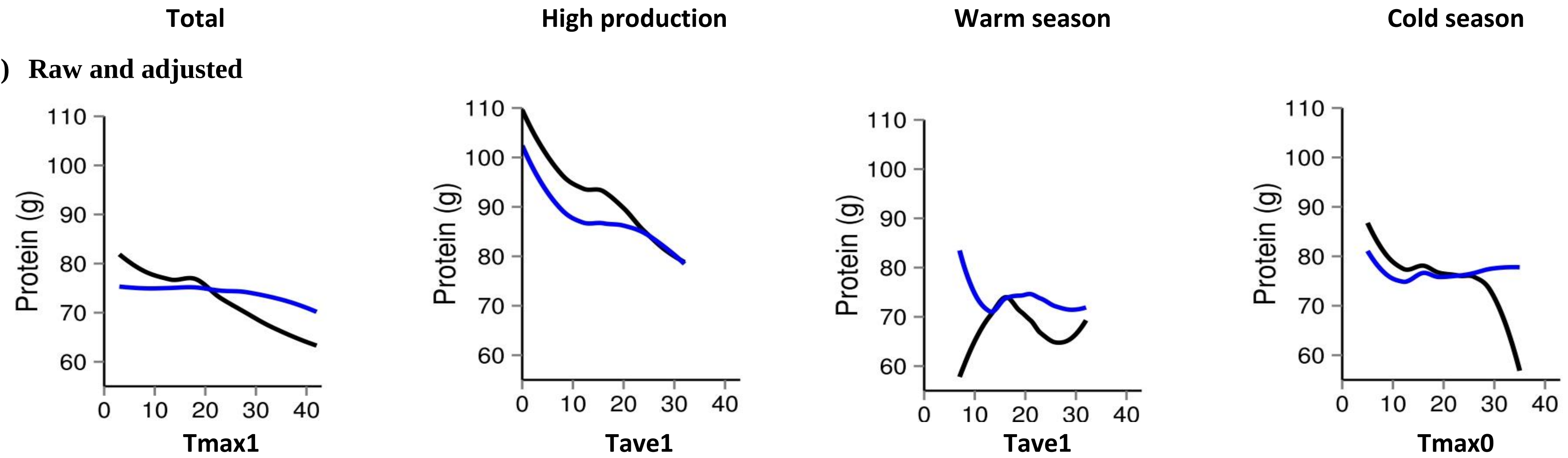
Daily protein yield show a production decrease with increasing temperatures when data from all and high productive animals are analyzed, with an almost stable production pattern in high productive animal between 11 and 22° C. High productive animals have a higher slope value than all animals in general and this higher slope is more clearly observed at high temperatures, as it was -14.56 at 30°C while it was -1.49 for all animals at the same temperature (Table 2.19). The same was reported for sheep (Carabaño *et al.,* 2013) at 29°C, who reported average temperature of the test day have slope value equal to -15.85 for high productive animals while slope value recorded for the total population at the same temperature was -0.49. Warm season data show an increase in daily protein yield up to about 18°C, and then it starts decreasing. On the contrary, cold season data show a protein yield increase with increasing temperatures with an almost stable pattern between 15 and 25°C, which means that a day with higher temperature in the cold season have a good effect on protein yield. As in the study of milk yield, temperature at which maximum production is reached could not be calculated except with warm season data, showing the highest production level at 17.78°C. Raw, adjusted and estimated data for high productive animal have the same pattern of variation of protein yield through temperature values. Results of the spline model and those obtained with polynomial models were not similar for warm and cold seasons data, while they were more similar to each other for total data and high productive animals at temperatures above 10° C (figure 2.4).

Table 2. 19. Derived values of the slopes of the relation between selected climatic variables and daily protein yield (g) at different temperatures (ºC) and temperatures at which the production is maximum, obtained by cubic polynomial models for total (TP), high (HP) and low (LP) productive animals, warm (HS) and cold (CS) seasons.

Protein (g)		Total	HP	LP	HS	CS
		T_{max1}	T_{ave1}	----	T_{ave1}	T_{max0}
Maximum		---	---		17.78	---
Derived	0	---	-21.36		---	---
	5	-5.11	-9.55		---	16.66
	10	-2.75	-2.01		13.29	5.43
	15	-1.21	1.26		4.06	-0.77
	20	-0.49	0.26		-2.39	-1.93
	25	-0.58	-5.01		-6.06	1.95
	30	-1.49	-14.56		-6.95	10.85
	35	-3.22	---		---	24.79
	40	-5.76	---		---	---

T_{max0}, T_{max1}: maximum temperature day of control and one day before; T_{ave1}: average temperature one day before control day.

a) Raw and adjusted



b) Estimated

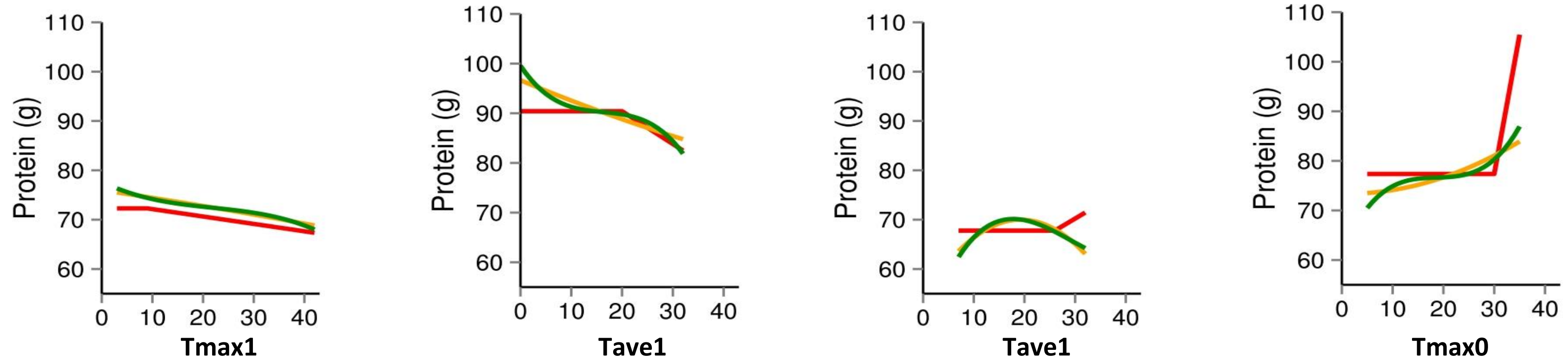


Figure 2. 4. a) Plots of raw (black line) and adjusted (blue line) protein yield *vs.* climatic variables. b) Estimated effects of climatic variables on protein yield using splines (red line) and quadratic (orange line) and cubic (green line) Legendre polynomials.

Table 2. 20. Posterior means, stander deviation (SD), Monte Carlo (MC) error and 95% high posterior density (HD95) intervals of the regression coefficients, animal and residual variances in the Legendre polynomial models for daily protein yield.

Protein (g)		Total	HP	LP	HS	CS
		T_{max1}	T_{ave1}	----	T_{ave1}	T_{max0}
Coef1	mean	-3.35	-5.93		-0.27	5.21
	SD	0.44	1.10		0.57	0.97
	MC Error	0.005	0.012		0.006	0.008
	HD95	-4.23 -2.50	-8.00 -3.76		-1.35 0.88	3.33 7.10
Coef 2	mean	-0.123	0.298		-4.45	1.36
	SD	0.42	1.15		0.59	0.92
	MC Error	0.005	0.012		0.006	0.010
	HD95	-0.989 0.668	-1.90 2.62		-5.57 -3.28	-0.42 3.17
Coef 3	mean	-0.83	-2.92		1.16	3.02
	SD	0.50	1.19		0.61	1.01
	MC Error	0.006	0.059		0.007	0.008
	HD95	-1.851 0.110	-5.15 -0.51		-0.041 2.349	1.08 5.01
Var_a	mean	0.19	0.16		0.17	0.20
	SD	0.005	0.01		0.005	0.007
	MC Error	0.0001	0.0003		0.0001	0.0002
	HD95	0.183 0.201	0.141 0.182		0.159 0.178	0.184 0.210
Var_e	mean	0.99	1.49		0.80	1.18
	SD	0.005	0.015		0.005	0.008
	MC Error	0.00007	0.0002		0.00007	0.0001
	HD95	0.977 0.995	1.46 1.52		0.786 0.806	1.17 1.20

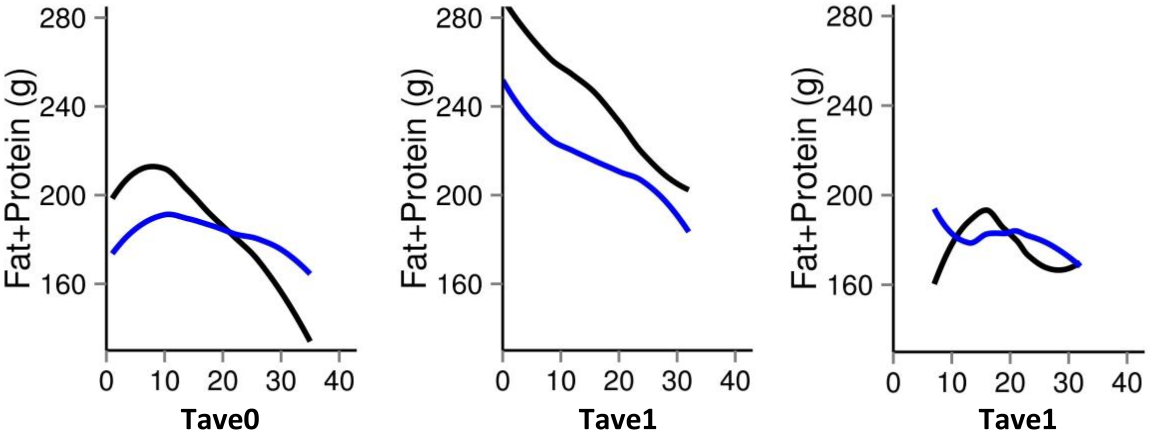
TP: total data, HP: high productive animals, LP: low productive animals, HS: warm season, CS: cold season. T_{max0}, T_{max1}: maximum temperature day of control and one day before, T_{ave1}: average temperature one day before control day; Coef 1; Coef 2; Coef 3: coefficients of regression of first, second and third Legendre polynomial; Var_a: Animal (permanent environmental) variance; Var_e: Residual variance.

Daily fat plus protein yield for the whole set and warm season data start to increase a little with temperature increasing and then production decrease. The maximum fat plus protein production takes place at 9.63°C for total data while it happens at 16.76°C for warm season data (Table 2.21 and Figure 2.5). Daily fat plus protein yield in high productive animals shows a decreasing pattern all over the whole range of temperatures and the slope value increases strongly at higher temperatures. Estimated values with polynomial models for fat plus protein yield appeared to have more stable pattern for total data at high temperature, while the decreasing in production is continuous for high productive animals and warm season data (Table 2.21 and figure 2.5). This pattern of decreasing production for high productive animal did not allow calculating temperature for the maximum production (Table 2.21). Raw and adjusted data for warm season data below

10° C show the opposite pattern (figure 2.5). The patterns of the, spline model for all and high productive data sets were more similar to that of the polynomial models. This means that for fitting data from both all and high productive data, it is not so important whether the model is linear or polynomial, since the raw and adjusted curves are descending almost strait lines.

Total **High production** **Warm season**

a) Raw and adjusted



b) Estimated

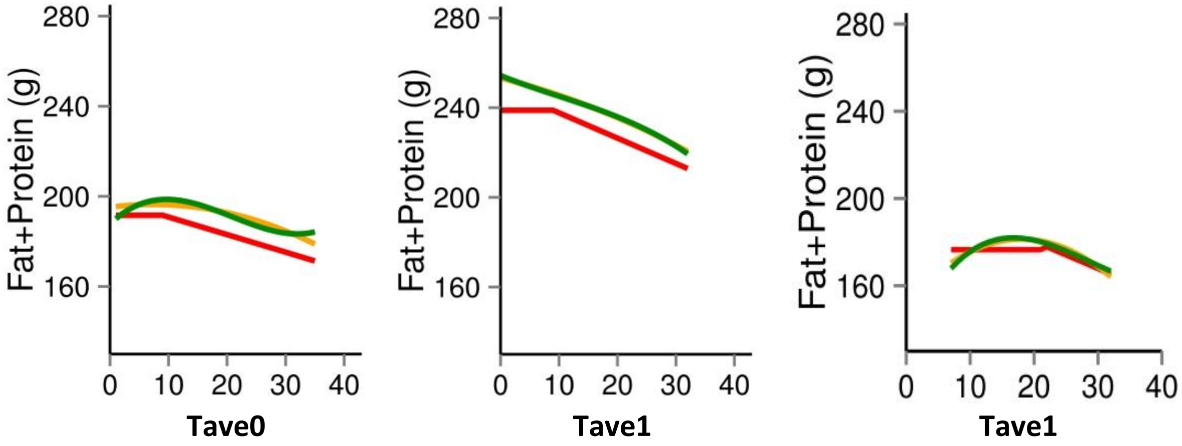


Figure 2. 5. a) Plots of raw (black line) and adjusted (blue line) fat plus protein yield *vs.* climatic variables. b) Estimated effects of climatic variables on fat plus protein yield using splines (red line) and quadratic (orange line) and cubic (green line) legendry polynomials.

Table 2. 21. Derived values of the slopes of the relation between selected climatic variables and daily fat plus protein yield (g) at different temperatures (ºC) and temperatures at which the production is maximum, obtained by cubic polynomial models for total (TP), high (HP) and low (LP) productive animals, warm (HS) and cold (CS) seasons.

Fat + Protein (g)		Total	HP	LP	HS	CS
		T_{ave0}	T_{ave1}	----	T_{ave1}	----
Maximum		9.63	---		16.76	
Derived	0	---	-8.68		---	
	5	21.56	-6.32		---	
	10	3.01	-5.51		26.80	
	15	-8.58	-6.26		7.06	
	20	-13.21	-8.57		-6.52	
	25	-10.88	-12.43		-13.94	
	30	-1.60	-17.84		-15.20	

T_{ave0}, T_{ave1}: average temperature day of control and one day before.

Table 2. 22. Posterior means, stander deviation (SD), Monte Carlo (MC) error and 95% high posterior density (HD95) intervals of the regression coefficients, animal and residual variances in the Legendre polynomial models for daily fat plus protein yield.

Fat + Protein (g)		Total	HP	LP	HS	CS
		T_{ave0}	T_{ave1}	----	T_{ave1}	----
Coef1	mean	-8.30	-16.38		-3.17	
	SD	0.85	1.91		1.04	
	MC Error	0.009	0.021		0.01	
	HD95	-9.94 -6.59	-20.00 -12.60		-5.13 -1.10	
Coef 2	mean	-4.46	-1.96		-9.26	
	SD	0.77	2.00		1.06	
	MC Error	0.008	0.021		0.01	
	HD95	-6.00 -3.01	-5.75 2.10		-11.31 -7.17	
Coef 3	mean	5.36	-1.06		2.57	
	SD	0.98	2.07		1.10	
	MC Error	0.01	0.028		0.01	
	HD95	3.341 7.224	-4.99 3.07		0.40 4.70	
Var_a	mean	1.60	1.52		1.36	
	SD	0.03	0.74		0.03	
	MC Error	0.0006	0.001		0.0006	
	HD95	1.540 1.657	1.38 1.67		1.30 1.41	
Var_e	mean	3.33	4.46		2.53	
	SD	0.02	0.04		0.02	
	MC Error	0.0002	0.0005		0.0002	
	HD95	3.295 3.356	4.38 4.55		2.50 2.56	

TP: total data, HP: high productive animals, LP: low productive animals, HS: warm season, CS: cold season.
T_{ave0}, T_{ave1}: average temperature day of control and one day before.
Coef 1; Coef 2; Coef 3: coefficients of regression of first, second and third Legendre polynomial.
Var_a: Animal (permanent environmental) variance; Var_e: Residual variance.

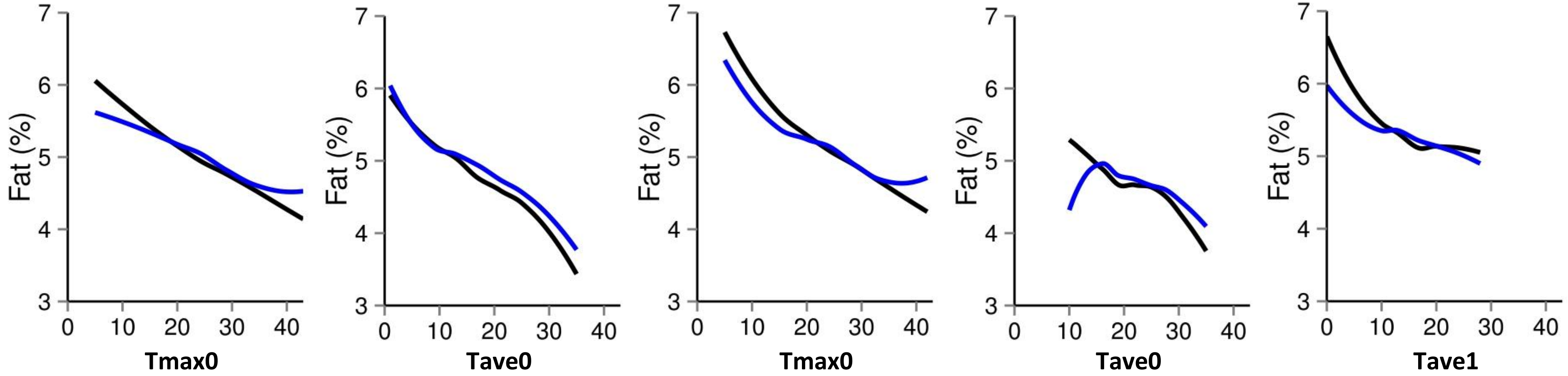
It is obvious that fat percentage decline highly with increasing temperatures for total, high, low productive animals and warm and cold seasons data (Table 2.23 and figure 2.6). This decline in fat percentage had not the same pace as for fat yield due to the increase of milk yield when temperature increases and the negative correlation between milk yield and fat content. On the contrary, Finocchiaro *et al.* (2005) found that fat and protein contents (%) were unaffected by heat stress in dairy sheep. The decrease in fat percentage appears to start very early, with no stable pattern in production. Slopes did not seem to differ between total and high productive animals for fat percentage. The same result was reported by Carabaño *et al.* (2013). The temperature at which the fat percentage is maximum could not be determined for total and warm season data sets, while it was 1.76, 0.04 and -3.02° C for high, low productive animals and cold season data, respectively (Table 2.23). The relations between raw and adjusted fat percentages and climatic variables show almost the same pattern for total, high, low productive animals, warm and cold seasons polynomial models. Spline model for warm and cold seasons data did not fit well and had a different pattern than polynomial models which seem to be more similar for raw and adjusted data (figure 2.6).

Table 2. 23. Derived values of the slopes of the relation between selected climatic variables and fat percentage at different temperatures (ºC) and temperature at which the production is maximum, obtained by cubic polynomial models for total (TP), high (HP) and low (LP) productive animals, warm (HS) and cold (CS) seasons.

Fat (%)	Total	HP	LP	HS	CS
	T_{max0}	T_{ave0}	T_{max0}	T_{ave0}	T_{ave1}
Maximum	---	1.76	0.04	---	-3.02
Derived					
0	---	---	---	---	0.18
5	-0.21	0.14	0.14	---	0.07
10	-0.28	-0.21	-0.09	-0.93	-0.07
15	-0.35	-0.45	-0.28	-0.38	-0.25
20	-0.41	-0.59	-0.42	-0.13	-0.45
25	-0.46	-0.61	-0.51	-0.18	-0.68
30	-0.50	-0.53	-0.55	-0.52	---
35	-0.54	-0.34	-0.54	-1.15	---
40	-0.57	---	-0.48	---	---

T_{max0}: maximum temperature day of control, T_{ave0}, T_{ave1}: average temperature day of control and one day before.

a) Raw and adjusted



b) Estimated

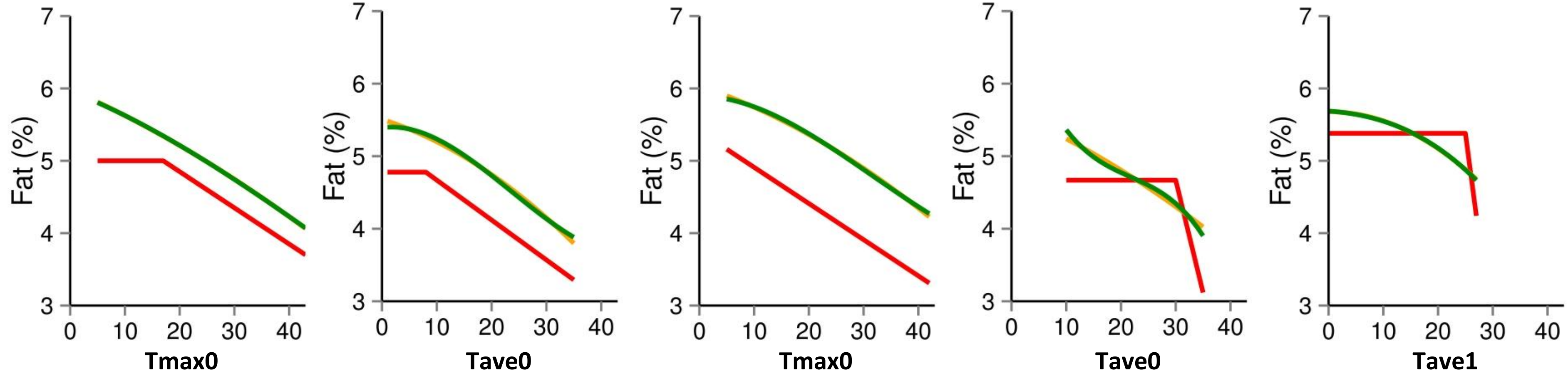


Figure 2. 6. a) Plots of raw (black line) and adjusted (blue line) fat percentage *vs.* climatic variables. b) Estimated effects of climatic variables on fat percentage using spline (red line) and quadratic (orange line) and cubic (green line) legendry polynomials.

Table 2. 24. Posterior means, stander deviation (SD), Monte Carlo (MC) error and 95% high posterior density (HD95) intervals of the regression coefficients, animal and residual variances in the Legendre polynomial models for daily fat percentage.

Fat (%)		Total	HP	LP	HS	CS
		T_{max0}	T_{ave0}	T_{max0}	T_{ave0}	T_{ave1}
Coef1	mean	-0.875	-0.84	-0.836	-0.61	-0.465
	SD	0.014	0.03	0.061	0.02	0.031
	MC Error	0.0001	0.0004	0.0008	0.0001	0.0003
	HD95	-0.903 -0.848	-0.90 -0.78	-0.952 -0.711	-0.64 -0.57	-0.524 -0.405
Coef 2	mean	-0.062	-0.14	-0.098	-0.04	-0.168
	SD	0.014	0.03	0.064	0.02	0.028
	MC Error	0.0002	0.0003	0.0008	0.0002	0.0003
	HD95	-0.090 -0.036	-0.20 -0.08	-0.222 -0.029	-0.07 0.00	-0.226 -0.116
Coef 3	mean	0.007	0.08	0.044	-0.12	-0.016
	SD	0.017	0.04	0.076	0.02	0.033
	MC Error	0.0002	0.0005	0.0008	0.0003	0.0003
	HD95	-0.028 0.040	0.009 0.160	-0.105 0.193	-0.17 -0.08	-0.079 0.049
Var_a	mean	0.179	0.15	0.187	0.160	0.180
	SD	0.005	0.009	0.026	0.006	0.008
	MC Error	0.0002	0.0002	0.0009	0.0002	0.0004
	HD95	0.170 0.189	0.132 0.167	0.138 0.240	0.148 0.170	0.165 0.195
Var_e	mean	1.316	1.24	1.08	1.02	1.526
	SD	0.006	0.01	0.028	0.007	0.011
	MC Error	0.00008	0.0002	0.0004	0.00009	0.0002
	HD95	1.304 1.328	1.218 1.266	1.026 1.134	1.009 1.036	1.505 1.548

TP: total data, HP: high productive animals, LP: low productive animals, HS: warm season, CS: cold season. T_{max0}: maximum temperature day of control, T_{ave0}, T_{ave1}: average temperature day of control and one day before; Coef 1; Coef 2; Coef 3: coefficients of regression of first, second and third Legendre polynomial. Var_a: Animal (permanent environmental) variance; Var_e: Residual variance.

Similar to what was observed for fat percentage, protein percentage show a continuous decreasing performance with increasing temperature for total, high, low productive animals, warm and cold seasons. Decline of protein content estimated with polynomial models shows that low productive animals decline somewhat faster (Table 2.25 and figure 2.7) , which is the opposite to what has been observed for other traits, including fat content, although the differences with the values estimated with the other data sets are not very high. Also similarly to what was seen in the case of fat content, the decline of protein content has a larger slope than that of protein yield, due to the same causes already explained above. Generally, the slope values estimated for protein percentage were lower than those estimated for fat percentage. Similar result was found by Carabaño *et al.* (2013). It is obviously that warm season has a lower protein percentage than cold season (figure 2.7). This result is in agreement with those reported by Bouraoui *et al.* (2002) which indicate a decreased in milk protein percentage for Mediterranean dairy cows as a result of summer heat stress in respect to spring season. It was not possible to determine the temperature of maximum protein content with the total, low productive and cold season data sets. For high productive and warm season data, the temperature at which this trait reached its maximum was -4.46 and 9.90° C, respectively (Table 2.25). The first value is not logic and, therefore shows a bad fitting of the model. The curves of protein contents vs temperature for raw and adjusted data were similar in all data set except in the warm season data below 13° C (figure 2.7).

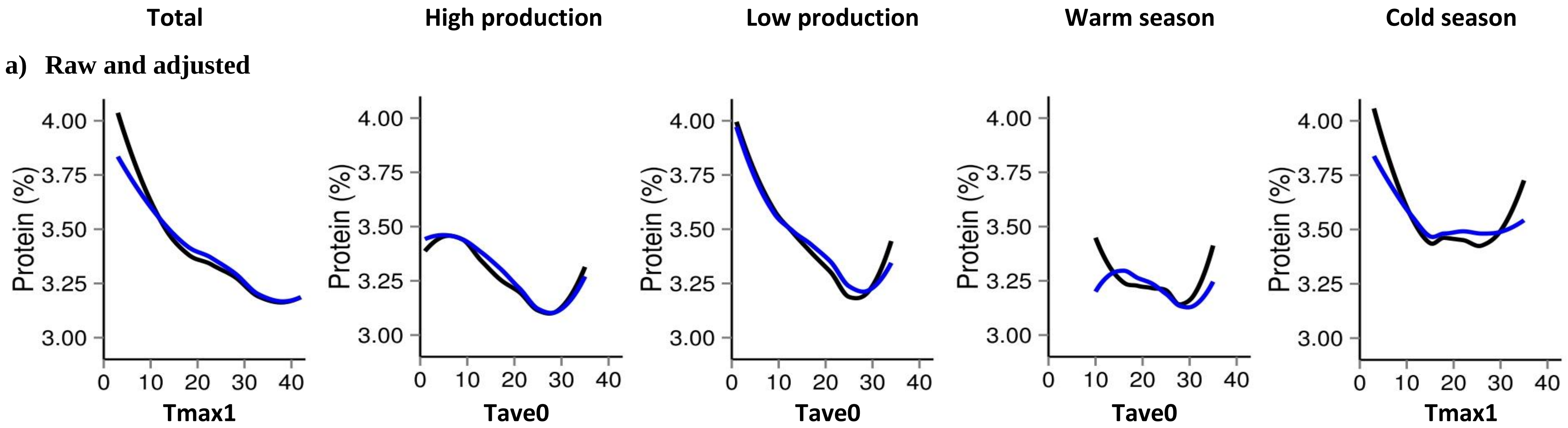
Table 2. 25. Derived values of the slopes of the relation between selected climatic variables and daily protein percentage at different temperatures (°C) and temperature at which the production is maximum, obtained by cubic polynomial models for total (TP), high (HP) and low (LP) productive animals, warm (HS) and cold (CS) seasons.

Protein (%)	Total	HP	LP	HS	CS
	T_{max1}	T_{ave0}	T_{ave0}	T_{ave0}	T_{max1}
Maximum	---	-4.46	---	9.90	---
Derived					
5	-0.17	-0.09	-0.18	---	-0.28
10	-0.18	-0.18	-0.21	0.10	-0.13
15	-0.19	-0.23	-0.23	-0.02	-0.04
20	-0.20	-0.24	-0.25	-0.10	-0.02
25	-0.21	-0.20	-0.26	-0.14	-0.07
30	-0.22	-0.12	-0.26	-0.16	-0.18
35	-0.23	-0.003	---	-0.13	-0.35
40	-0.24	---	---	---	---

T_{max1}: maximum temperature one day before day of control, T_{ave0}: average temperature day of control.

In contrast to the results reported for dairy cattle, our results show that there is not a comfortable zone in which the yield is constant. Furthermore, in our case, the decrease in fat, protein, fat plus protein yield, fat and protein percentage start much earlier, whereas in a genetic study of the Murciano-Granadina and Payoya goats (another two Spanish breeds of goats), Menendez-Buxadera *et al.* (2012) reported an effect of heat stress on dairy traits at a THI higher than 20 for Murciano-Granadina and Payoya dairy goats. Moreover, the pattern of fat and fat plus protein yield for the complete data set and the pattern of fat yield for high productive animals (figure 2.3 and 2.5) suggest that goats are also affected by cold stress.

a) Raw and adjusted



b) Estimated

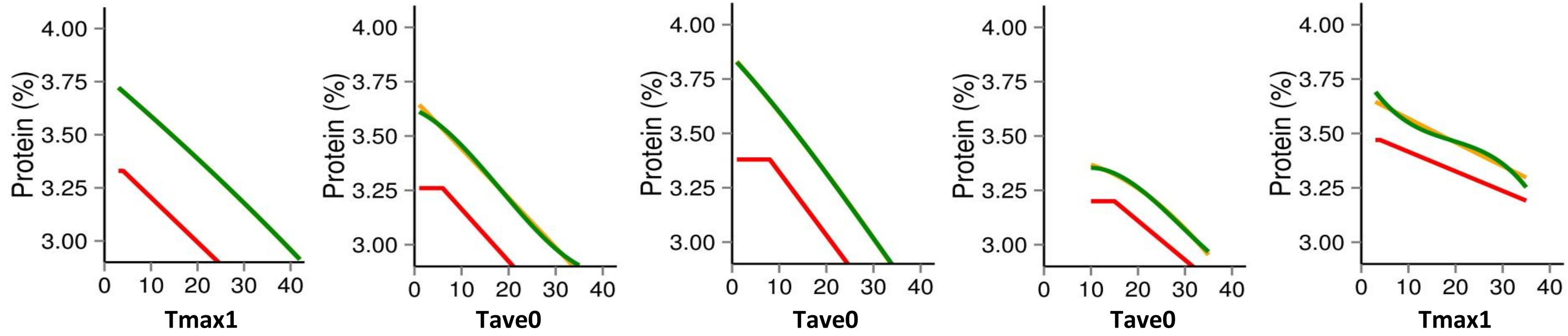


Figure 2. 7. a) Plots of raw (black line) and adjusted (blue line) protein percentage *vs.* climatic variables. b) Estimated effects of climatic variables on protein percentage using splines (red line) and quadratic (orange line) and cubic (green line) legendry polynomials.

Table 2. 26. Posterior means, stander deviation (SD), Monte Carlo (MC) error and 95% high posterior density (HD95) intervals of the regression coefficients, animal and residual variances in the Legendre polynomial models for daily protein percentage.

Protein (%)		Total	HP	LP	HS	CS
		T_{max1}	T_{ave0}	T_{ave0}	T_{ave0}	T_{max1}
Coef1	mean	-0.404	-0.386	-0.470	-0.208	-0.174
	SD	0.006	0.013	0.036	0.008	0.012
	MC Error	0.00007	0.0001	0.0004	0.00009	0.0001
	HD95	-0.416 -0.391	-0.410 -0.360	-0.540 -0.399	-0.224 -0.192	-0.198 -0.150
Coef 2	mean	-0.012	-0.002	-0.018	-0.039	0.001
	SD	0.006	0.012	0.034	0.008	0.011
	MC Error	0.00006	0.0001	0.0004	0.00008	0.0001
	HD95	-0.025 -0.001	-0.026 0.022	-0.085 0.047	-0.056 -0.024	-0.019 0.023
Coef 3	mean	-0.001	0.033	0.004	0.014	-0.045
	SD	0.007	0.015	0.044	0.01	0.013
	MC Error	0.00007	0.0002	0.0005	0.0001	0.0001
	HD95	-0.016 0.013	0.003 0.063	-0.082 0.091	-0.005 0.035	-0.071 -0.018
Var_a	mean	0.057	0.055	0.046	0.051	0.070
	SD	0.001	0.003	0.006	0.001	0.002
	MC Error	0.00003	0.00004	0.0002	0.00003	0.00005
	HD95	0.055 0.060	0.050 0.060	0.034 0.058	0.049 0.054	0.067 0.074
Var_e	mean	0.205	0.192	0.254	0.187	0.200
	SD	0.001	0.002	0.007	0.001	0.001
	MC Error	0.00001	0.00002	0.00009	0.00002	0.00002
	HD95	0.203 0.207	0.189 0.196	0.241 0.267	0.184 0.189	0.197 0.202

TP: total data, HP: high productive animals, LP: low productive animals, HS: warm season, CS: cold season.
T_{max1}: maximum temperature one day before day of control, T_{ave0}: average temperature day of control.
Coef 1; Coef 2; Coef 3: coefficients of regression of first, second and third Legendre polynomial.
Var_a: Animal (permanent environmental) variance; Var_e: Residual variance.

2. 5. Conclusions

Production of Florida dairy goats is most affected by the climatic conditions of the day of production or one day before. Maximum and average temperatures explain the change in dairy traits caused by climatic effect better than THI index. Low productive animals do not seem to be very much affected by these climatic variables in respect to fat, protein and fat plus protein yields, while high productive animals seem to be much affected by climate in respect to fat, protein and fat plus protein yields. Daily milk yields increase as the temperature increases. On the contrary, daily fat, protein and fat plus protein yield and fat and protein percentage decrease when temperature increase. Results suggest that, contrary to what has been observed in dairy cattle, this breed of goats does not show what has been called a comfortable zone, or range of temperatures, in which dairy traits are not affected. The contents, as well as the yields of fat and protein start suffering the effects of heat stress at a low temperature.

2. 6. References

Baccari Júnior, F.; Gonçalves, H.C.; Muniz, L.M.R.; Polastre, R. and Head, H.H. 1996. Milk production, serum concentrations of thyroxine and some physiological responses of Saanen-native goats during thermal stress. Veterinária e Zootecnia., 8: 9-14.

Berman, A.J. 2005. Estimates of heat stress relief needs for Holstein dairy cows. J. Anim. Sci., 83:1377-1384.

Bianca, W. 1962. Relative importance of dry- and wet-bulb tempera- tures in causing heat stress in cattle. Nature, 195: 251–252.

BOE. 2005. REAL DECRETO 368/2005, de 8 de abril, por el que se regula el control oficial del rendimiento lechero para la evaluacín genética en lasespecies bovina, ovina y caprina. Ministerio de agricultura, Pesca y alimentación. 97: 13918- 13937.

Bolle, H.J. 2003. Climate, climate variability and impacts in the Mediterranean area: an overview. In: Mediterranean Climate: Variability and Trends. Ed. Bolle, H.J. Springer, New York, pp. 5-86.

Bouraoui, R.; Lahmar, M.; Majdoub, A.; Djemali, M. and Belyea, R. 2002. The relationship of temperature- humidity index with milk production of dairy cows in a Mediterranean climate. Anim. Res., 51: 479-491.

Carabaño, M.J.; Ramón, M.; Abo-Shady, H.M.; Pérez-Guzmán, M.D.; Serrano, M.; Díaz, C.; Molina, A.; Menéndez-Buxadera, A.; Bahchaga, K.; Pérez-Cabal, M.A. and Serradilla, J.M. 2013. Estrés térmico en razas autóctonas de rumiantes lecheros. Asociación Interprofesional para el Desarrollo Agrario (AIDA). XV Jornadas sobre Producción Animal. XV(2): 451-452.

Dikmen, S. and Hansen, P.J. 2009. Is the temperature-humidity index the best indicator of heat stress in lactating dairy cows in a subtropical environment? J. Dairy Sci., 92: 109–116.

Du Preez, J.H.; Giesecke, W.H. and Hattingh, P.J. 1990. Heat stress in dairy cattle and other livestock under Southern African conditions. I. Temperature-humidity index mean values during the four main seasons. Onderstepoort J. Vet. Res., 57: 77-86.

Finch, V.A. 1984. Heat as a stress factor in herbivores under tropical conditions. In: Gilchrist, F.M.C., Mackie, R.I. (Eds.), Herbivore Nutrition in the Subtropics and Tropics. The Science Press, Graighall, South Africa, pp. 89–105.

Finocchiaro, R.; Van Kaam, J.B.C.H.M.; Portolano, B. and Misztal, I. 2005. Effect of heat stress on production of mediterranean dairy sheep. J. Dairy Sci., 88: 1855–1864.

Igono, M.O.; Bjotvet, G. and Sanford-Crane, H.T. 1992. Environmental profile and critical temperature effects on milk production of Holstein cows in desert climate. Int. J. Biometeorol., 36: 77–87.

Johnson, H.D.; Ragsdale, A.C.; Berry, I.L. and Shanklin, M.D. 1962. Effect of various temperature humidity combinations on milk production of Holstein cattle. Missouri Agric. Exp. Sta. Res. Bull., 791.

Kelly, C.F. and Bond, T.E. 1971. Bioclimatic factors and their measurement: A guide to environmental research on animals. National Academy of Sciences, Washington, DC. pp. 71-92.

Menéndez-Buxadera, A.; Molina, A.; Arrebola, F.; Clemente, I. and Serradilla, J.M. 2012. Genetic variation of adaptation to heat stress in two Spanish dairy goat breeds. J. Anim. Breed. genet., 129: 306-315.

NRC, National Research Council. 1971. A guide to environmental research on animals. National Academy of Sciences, Washington, DC. pp. 274.

Oseni, S. and Bebe, O. 2010. Climate change, genetics of adaptation and livestock production in low-input systems. 2nd International Conference: Climate, Sustainability and Development in Semi-arid Regions. Fortaleza - Ceará, Brazil. pp. 12.

Ravagnolo, O.; Misztal, I. and Hoogenboom, G. 2000. Genetic Component of Heat Stress in Dairy Cattle, Development of Heat Index Function. J. Dairy Sci., 83: 2120–2125.

SAS. 2009. SAS User's Guide: Statistics. Version 9.2. SAS Inst. Inc., Cary, NC., USA. pp. 7869.

Sevi, A. and Caroprese, M. 2012. Impact of heat stress on milk production, immunity and udder health in sheep: A critical review. Small Rum. Res., 107: 1–7.

Shafie, M.M.; Murad, H.M.; El-Bedawy, T.M. and Salem, S.M. 1994. Effect of heat stress on feed intake, rumen fermentation and water turnover in relation to heat tolerance response by sheep, Egypt. J. Anim. Prod., 31(2): 317–327.

Silanikove, N. 2000. Effects of heat stress on the welfare of extensively managed domestic ruminants. Livestock Prod. Sci., 67: 1–18.

St-Pierre, N.R.; Cobanov, B. and Schnitkey, G. 2003. Economic losses from heat stress by US livestock industries. J. Dairy Sci., 86(E Suppl.): E52–E77.

West, J.W.; Mullinix, B.G. and Bernard, J.K. 2003. Effects of Hot, Humid Weather on Milk Temperature, Dry Matter Intake, and Milk Yield of Lactating Dairy Cows. J. Dairy Sci., 86: 232–242.

CHAPTER 3

Genetic components of the response of dairy traits to heat stress in Florida goats

3. 1. Abstract

A study of the effect of heat stress on dairy traits in goats of Florida breed was undertaken with the objective to estimate the environmental and genetic (co)variance components of heat stress tolerance. The data set analyzed included 100,787 test-day records belonging to 10,283 does, offspring of 1842 does and 218 bucks, in 20 flocks, collected between 2006 and 2012. Traits investigated were daily milk, fat, protein and fat-plus-protein yields and fat and protein contents. Monthly test-day records of milk yield and composition were combined with weather data from meteorological stations located near the farms, registered the same test day. A reaction norm model (RNM) was used to estimate genetic and permanent environmental (co)variance components in respect to three independent climatic variables (daily maximum and average temperature and an index combining temperature and relative humidity “THI index”). The genetic correlations between the intercept and the slope of the responses to the climatic variables of each dairy trait studied were negative. Heritability estimates of dairy traits showed a negative trend with increasing THI, maximum and average temperature values. This decrease in heritability was much more marked in the case of average temperature. The genetic correlations between first point and different points of each trait in the scales of the climatic variables decreased as a function of the distance between these points, reaching values below 0.80 for both THI and maximum temperature and below 0.60 for average temperature when computed correlation between the first and last points. These results provide evidence on dairy performance at different THI, maximum or average temperatures behaving as genetically different traits and on selection for better milk performance reducing heat stress tolerance. Estimated breeding values of the animals for the dairy traits studied showed different patterns of variation through the trajectories of values of the climatic variables. Using, therefore, reaction models makes possible to select animals for their response to heat stress.

3. 2. Introduction

Artificial selection to increase milk yield has been demonstrated to reduce heat tolerance in dairy cattle (Ravagnolo and Misztal, 2000; Bohmanova *et al.*, 2007) and dairy sheep (Finocchiaro *et al.*, 2005). The estimated genetic correlation between milk yield and heat tolerance ranges from -0.3 to -0.4 (Ravagnolo and Misztal, 2000 and 2002) Therefore, a continual selection for increase milk production results in a decreasing heat tolerance.

Studies on the genetic parameters for the response to heat stress in small ruminants are very scarce. The only two available works are that of Finocchiaro *et al.* (2005) for dairy sheep and that of Menéndez-Buxadera *et al.* (2012) for dairy goats. Dairy goats have been traditionally considered to show better adaptation to harsh environmental conditions (Silanikove, 2000). However, there are evidences that their performances are also affected by heat stress. Menéndez-Buxadera *et al.* (2012) reported the first indication of the negative effect of heat stress on dairy performance in goats. According to these authors, the estimated genetic correlations (r_{g}) between dairy performances under different combinations of temperature and relative humidity (summarized in an index combining both climatic variables named THI) decrease as the distance between points in the THI scale rises. These r_{g} reached values below 0.80, which is an evidence of genotype by environment interactions (Robertson, 1959). They also indicate that selection for better milk performance reduces heat stress tolerance. Moreover, Kolmodin and Bijma (2004) referred that the ratio between genetic variances of the intercepts and the slopes ($\sigma^2_{\mathrm{as}}/\sigma^2_{\mathrm{ao}}$) indicates the magnitude of this interaction. Another view for Mulder (2007) considered G×E relevant when genetic correlations between the traits expressed at different environment is below 0.60

According to the reaction norm concept, defined by De Jong (1990) as the range of phenotypic expression of a given genotype in response to systematic changes in a continuous environmental variable, the reaction norm models (RNM) could provide deep understanding of the genetic components of heat stress tolerance. Moreover, selection of animals according to the type of response most suitable to specific climate conditions and production systems could be achieved by estimating the response of the animals to stress produced by different combinations of temperature and humidity using RNM. Menéndez-Buxadera *et al.* (2012) described three types of responses of the estimated breeding values (EBV) to heat stress: (i) Robust animals, which show a stable performance throughout the THI trajectory (with an average intercept and an average slope); (ii) Tolerant animals, which show a low genetic level (intercept) and a high genetic capability to adapt to climatic stress (slope); and (iii) Non-tolerant animals, which manifest a high genetic level (intercept) and very low capability to adapt to stressful climate conditions (slope).

Most genetic analysis performed to study heat stress in dairy animals used THI index as a measure of the level of heat stress. However, Carabaño *et al.* (2013) found that maximum and average temperature models fitted better than THI model.

The aim of this study was to estimate the environmental and genetic (co)variance components (VC) of heat stress tolerance in the Spanish local breed of Florida dairy goats, using for the analyses a reaction norm model and THI, maximum and average temperature as climatic variables.

3. 3. Materials and Methods

A total of 185,675 test-day records of daily milk yield (DMY), daily protein percentage (DPP), daily fat percentage (DFP) and daily dry matter percentage (DDMP), collected between January 2006 and February 2012, from Florida goats were used as initial data set to estimate the environmental and genetic (co)variance components of heat stress tolerance. Data were provided by the Asociación Nacional de Criadores de Ganado Caprino de Raza Florida (ACRIFLOR). Raw data were edited and validated, according to ICAR standards (BOE, 2005), excluding records collected during the first 10 days after kidding and those recorded after 240 days. Records from does having a single record per lactation were also deleted. Subsequently, daily fat, protein and fat plus protein yields were calculated. The meteorological data set, provided by the Meteorological State Agency "Agencia Estatal de Meteorología -AEMET" and System of Agroclimatic information for Irrigation "Sistema de Información Agroclimática para el Regadío -SiAR", belonging to the Spanish Ministry of Agriculture, Food and Environment. They consisted of daily maximum and minimum temperatures (°C) and relative humidity (%) from the meteorological station located nearest (<22 Km) to each farm. Subsequently, daily average temperature (Tave) and relative humidity (RHave) were calculated from these maximum and minimum values. An index of temperature and relative humidity (THI), similar to the one initially proposed by Kelly and Bond (1971) was calculated by combining maximum temperature (Tmax °C) and average relative humidity (RH %), following the adaptation of Finocchiaro *et al.* (2005) to Mediterranean climatic conditions:

$$THI= [T-(0.55\times(1-RH))\times(T-14.4)]$$

Figure 3.1 shows the variation in THI index, maximum temperature (Tmax) and average relative humidity (RHave) values throughout the year in the region where the production data were collected. Daily test-day and meteorological data were merged, resulting in 100,787 test-day records corresponding to 10,283 goats, offspring of 1842 does and 218 bucks (average of 14.4 daughters per buck with the number ranging from 1 to 102), making a total of 3119 half-sibs (13% progeny of AI bucks) distributed in 20 flocks well connected through the progeny of 6 sires. The total number of animals in the pedigree file was 10,828. Table 3.1 shows a summary of the basic statistics of the final data set.

Table 3. 1. Number of records and descriptive statistics (mean±standard error) of the data set used for the analyses.

	Mean
N. records	100 787
N. animals	10 283
N. flocks	20
Daily milk yield (g)	2351±1089
Daily protein content (%)	3.33±0.57
Daily protein yield (g)	72.29±37.81
Daily fat content (%)	5.00±1.39
Daily fat yield (g)	106.45±56.21
Daily fat+protein yield (g)	191.60±82.13

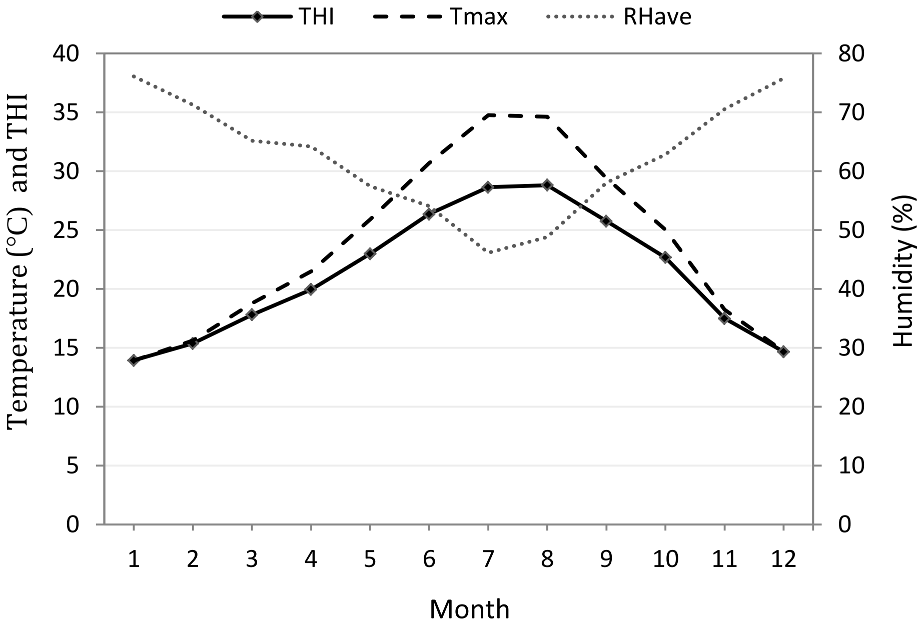


Figure 3. 1. Variation through the year of average values of THI, maximum temperature (Tmax) and average relative humidity (RHave).

Statistical analysis

Initially, a general linear model (SAS, 2009) was used to determine the fixed factors significantly affecting the dependent variables. The model included herd-year-month of test day (650 levels), age-lactation number (24 levels), milking frequency (1 and 2 per day) and climatic variables (THI, maximum and average temperatures) as covariables. ASREML software (Gilmour *et al.*, 2000) was used to calculate VC and estimated breeding values (EBV). The VC and EBV were estimated at each point along the range of THI, maximum temperature (Tmax) and average temperature (Tave) values by means of a random regression model, assuming that the phenotypic expression of each trait in each animal is the consequence of general (intercept) and specific (slope) correlated values of genetic and permanent effects. Similarly to the approach taken by Finocchiaro *et al.* (2005) and Menéndez-Buxadera *et al.* (2012), variance components were estimated for all lactations at once, instead of estimating them separately for each lactation, because of low number of animals and the scarce pedigree information available. The model used was as following:

$$y_{ijklmnopq} = \mathrm{HD}_i + \mathrm{FM}_j + Age_k.Lac_l + DL_m + \sum_{r=0}^{1} \Phi_r b_{nr} + \sum_{r=0}^{1} \Phi_r a_{or} + \sum_{r=0}^{1} \Phi_r p_{pr} + e_{ijklmnopq}$$

where, $\mathrm{y}_{\mathrm{ijklmn}opq}$ is the observed dependent variable for each trait; $\mathrm{HD_i}$ is the effect of the i^{th} herd-date of recording (i = 650 levels); $\mathrm{FM_j}$ is j^{th} frequency of milking (j = 2 levels); $\mathrm{Age}_k.\mathrm{Lac}_l$ is the effect of the interaction between k^{th} age at parturition (k = 12 levels) and l^{th} lactation number (l = 5 levels); $\mathrm{DL_m}$ is m^{th} day of lactation (m = 231 levels); $\mathrm{b_{nr}}$ is a fixed first-order Legendre polynomial coefficients and the Φ_r terms are the Legendre polynomial covariables evaluated at the corresponding THI, Tmax or Tave value standardized in the interval [-1, 1]; a_{or} and p_{pr} are the random regression coefficients for animal genetic effects and permanent environmental effects; e is the residual random term with homogeneous variance. The expected (co)variance components of y are estimated by:

$$V(y) = \Phi_i \begin{bmatrix} \mathbf{A}\sigma_{ao}^2 & \mathbf{A}\sigma_{aos} \\ \mathbf{A}\sigma_{aso} & \mathbf{A}\sigma_{as}^2 \end{bmatrix} \Phi_i' + \Phi_i \begin{bmatrix} \mathbf{I}_p\sigma_{po}^2 & \mathbf{I}_p\sigma_{pos} \\ \mathbf{I}_p\sigma_{pso} & \mathbf{I}_p\sigma_{ps}^2 \end{bmatrix} \Phi_i' + \mathbf{R}$$

The Φ_{i} elements are matrices containing the coefficients of the first-order Legendre polynomial modelling THI, Tmax or Tave values in a standardized scale form. In this model, the variance and covariance structure contains elements related to a function of the intercept ($\mathrm{\sigma}_{\mathrm{o}}^2$) and the slope ($\mathrm{\sigma}_{\mathrm{s}}^2$) of heat tolerance for genetic (*a*) and permanent environmental (*p*) effects. The terms $\mathrm{\sigma}_{\mathrm{aos}}$ and $\mathrm{\sigma}_{\mathrm{pos}}$ are the covariance between intercept and slope for *a* and *p*, respectively. **A** is the numerator relationship matrix between the animals; $\mathbf{I}_p$ is the identity matrix for permanent environmental effects; **R** is the residual variance matrix. In this model, it is possible to estimate additive genetic variance ($\sigma_{a_i}^2$), permanent environmental variance ($\sigma_{p_i}^2$), heritability (h_i^2), genetic correlations ($r_{a_{ij}}$) and environmental permanent correlations ($r_{p_{ij}}$) for each trait and for all points of the trajectory of the environmental (climatic variables) scale using the elements of Φ_i for the corresponding level of THI, Tmax or Tave, following the procedure of Jamrozik and Schaeffer (1997) as:

$$\sigma_{a_i}^2 = \Phi_i \, \mathrm{G} \, \Phi_i' \qquad \sigma_{p_i}^2 = \Phi_i \, \mathrm{P} \, \Phi_i'$$

$$h_i^2 = \frac{\sigma_{a_i}^2}{\sigma_{a_i}^2 + \sigma_{p_i}^2 + \sigma_e^2}$$

$$\sigma_{a_{ij}} = \Phi_i \, \mathrm{G} \, \Phi_j' \qquad \sigma_{p_{ij}} = \Phi_i \, \mathrm{P} \, \Phi_j'$$

$$r_{a_{ij}} = \frac{\sigma_{a_{ij}}}{\sqrt{\sigma_{a_i}^2 \, \sigma_{a_j}^2}}$$

$$r_{p_{ij}} = \frac{\sigma_{pe_{ij}}}{\sqrt{\sigma_{p_i}^2 \, \sigma_{p_j}^2}}$$

where, G is the (co)variance matrix for the animal coefficients, P is the (co)variance matrix for permanent environment coefficients, σ_e^2 is the residual variance, $\sigma_{a_{ij}}$ is the additive genetic covariance and $\sigma_{p_{ij}}$ the permanent environmental covariance between *i* and *j* point of the trajectory of the environmental scale. Moreover, estimates of breeding values for any animal (*m*) can be obtained at any point of the trajectory of THI, Tmax or Tave from:

$$\mathrm{EBV}_m^i = \Phi_i \mathrm{a}_m'$$

where, vector a_m contains the solutions for the additive genetic random regression coefficients corresponding to animal *m* and vector Φ_i contains the first-order Legendre polynomial coefficients evaluated at the *i* point for THI, Tmax or Tave.

3. 4. Results and discussion

All the effects included in the preliminary analyses carried out with the GLM were significant for all traits studied. The phenotypic effects of THI index, maximum (Tmax) and average (Tave) temperature on dairy milk and milk components yields and daily contents of milk components are shown in Figure 3.2. All observed trends for contents traits are negative. All studied traits show the similar trends for THI, Tmax and Tave, except daily milk production which shows a different pattern of response for each climatic variable.

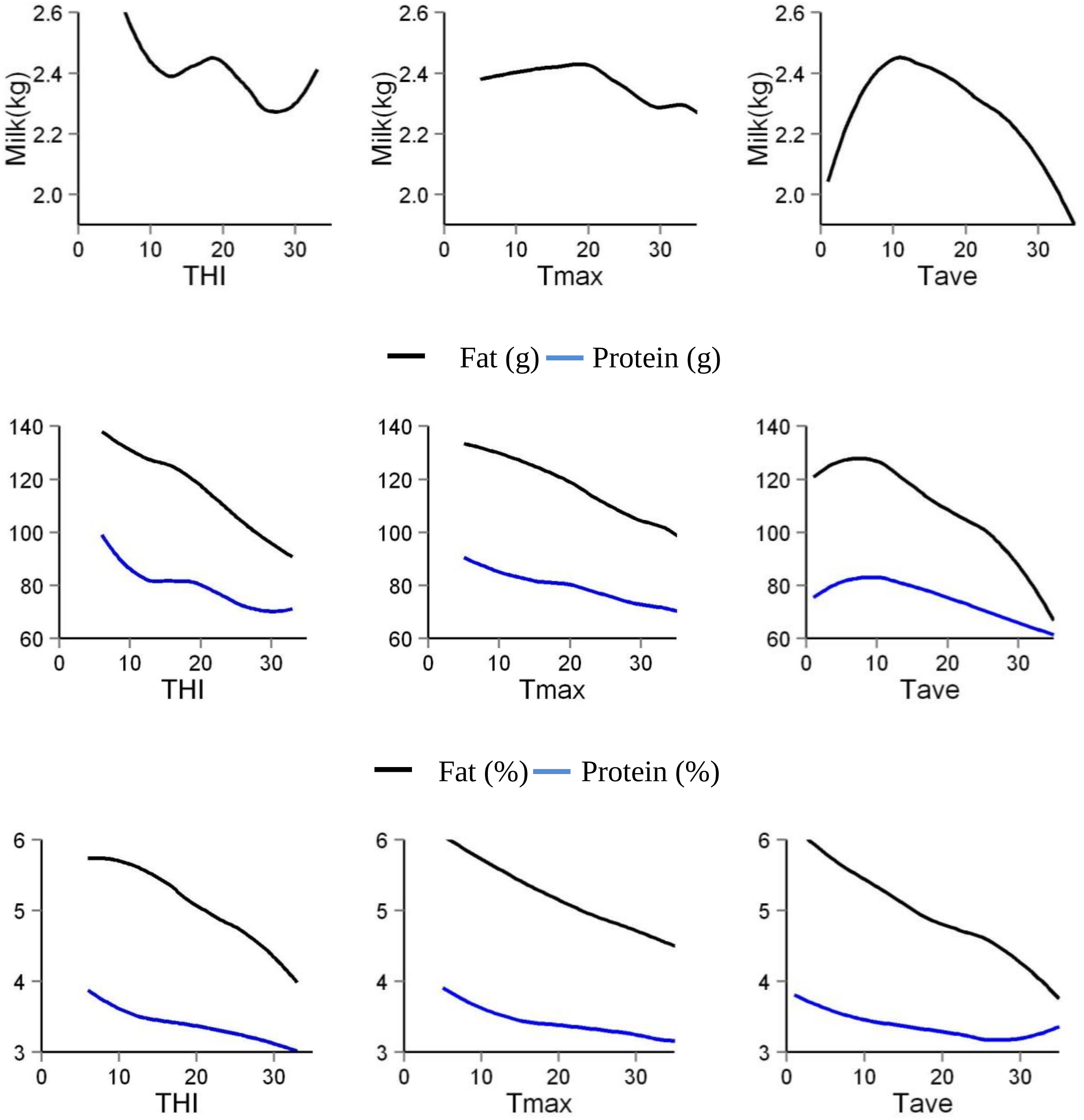


Figure 3. 2. Phenotypic effects of temperature-humidity index (THI), maximum (Tmax) and average (Tave) temperature on daily milk and milk components yields and daily contents of milk components.

Estimated variance components for the dairy traits studied are shown in Table 3.2 for THI model, Table 3.3 for Tmax model and Table 3.4 for Tave model. All variance components estimated with THI model, 95 % of those estimated with Tmax model and 90 % of the ones estimated with Tave model had an estimate ⁄ standard error ratio higher than 2 which, according to ASREML reference manual (Gilmour *et al.*, 2000), is the threshold for the estimates to be considered reliable.

Generally, the genetic variances for the intercepts (σ^2_{ao}, general heat stress tolerance) were much higher than those of the slopes (σ^2_{as}, specific heat stress tolerance) for all models. The genetic covariance between intercepts and slopes was negative for all traits studied in the three models. The negative correlation between the genetic intercept (σ^2_{ao}) and the slope (σ^2_{as}) is an evidence for genotype by environment interaction (G×E) and provides an indication that selection for better milk performance will reduce heat stress tolerance. Similar results were obtained by Menéndez-Buxadera *et al.* (2012) for content traits in Murciano-Granadina goats and for yield traits in Payoya goats.

Table 3. 2. Estimates of (co)variance for intercept (o) and slope (s) and their correlation, for genetic (σ^2_{ao} , σ^2_{as} , σ_{aos} and r_{aos}) and permanent environmental effects (σ^2_{po} , σ^2_{ps} , σ_{pos} and r_{pos}) of dairy traits for THI model.

Parameters	Daily milk yield (Kg)	Daily fat yield (g)	Daily Protein yield(g)	Daily fat+protein yield (g)	Daily fat content (%)	Daily Protein content (%)
σ^2_{ao}	293	540	248	1497	0.375	0.102
σ^2_{as}	24	46	16	110	0.039	0.011
$\sigma^2_{\mathrm{as}}/\sigma^2_{\mathrm{ao}}$	**0.082**	**0.085**	**0.065**	**0.074**	**0.103**	**0.106**
σ_{aos}	-57	-95	-43	-263	-0.031	-0.008
r_{aos}	**-0.682**	**-0.603**	**-0.671**	**-0.648**	**-0.256**	**-0.240**
σ^2_{po}	299	614	298	1717	0.091	0.014
σ^2_{ps}	92	175	60	440	0.034	0.019
$\sigma^2_{\mathrm{ps}}/\sigma^2_{\mathrm{po}}$	**0.308**	**0.285**	**0.201**	**0.256**	**0.378**	**1.324**
σ_{pos}	-43	-213	-62	-489	-0.043	-0.008
r_{pos}	**-0.259**	**-0.650**	**-0.466**	**-0.562**	**-0.770**	**-0.486**

Comparing the results of the three models, THI model has the highest correlation between the genetic intercept (σ^2_{ao}) and slope (σ^2_{as}) for all trait studied except for daily protein yield which is a little higher in Tave model. According to Kolmodin and Bijma (2004), the ratio between genetic variances of the intercepts and the slopes ($\sigma^2_{\mathrm{as}}/\sigma^2_{\mathrm{ao}}$) indicates the magnitude of the G×E interaction. This ratio has a higher value in the Tave model for all traits studied. Similarly to what was found by Menéndez-Buxadera *et al.*

(2012), our $\sigma^2_{\mathrm{as}}/\sigma^2_{\mathrm{ao}}$ ratios for content variables are higher values than those for yield variables in both THI and Tmax models. The correlation between the permanent environment intercept (σ^2_{po}) and slope (σ^2_{ps}) is negative for all traits in the three models, which is in agreement with the findings of Finocchiaro *et al.* (2005) and Menéndez-Buxadera *et al.* (2012).

Table 3. 3. Estimates of (co)variance for intercept (o) and slope (s) and their correlation, for genetic (σ^2_{ao} , σ^2_{as} , σ_{aos} and r_{aos}) and permanent environmental effects (σ^2_{po} , σ^2_{ps} , σ_{pos} and r_{pos}) of dairy traits for maximum temperature model.

Parameters	Daily milk yield (Kg)	Daily fat yield (g)	Daily Protein yield (g)	Daily fat+protein yield (g)	Daily fat content (%)	Daily Protein content (%)
σ^2_{ao}	264	493	227	1368	0.362	0.099
σ^2_{as}	25	47	16	114	0.037	0.010
$\sigma^2_{\mathrm{as}}/\sigma^2_{\mathrm{ao}}$	**0.095**	**0.096**	**0.070**	**0.083**	**0.101**	**0.100**
σ_{aos}	-50	-86	-38	-237	-0.027	-0.006^{ns}
r_{aos}	**-0.615**	**-0.562**	**-0.626**	**-0.599**	**-0.235**	**-0.193**
σ^2_{po}	284	520	270	1502	0.073	0.012
σ^2_{ps}	86	158	55	400	0.030	0.019
$\sigma^2_{\mathrm{ps}}/\sigma^2_{\mathrm{po}}$	**0.303**	**0.304**	**0.204**	**0.266**	**0.417**	**1.642**
σ_{pos}	-22	-166	-48	-376	-0.030	-0.003^{ns}
r_{pos}	**-0.141**	**-0.578**	**-0.393**	**-0.485**	**-0.643**	**-0.232**

^{ns} not significant.

Table 3. 4. Estimates of (co)variance for intercept (o) and slope (o) and their correlation for genetic (σ^2_{ao} , σ^2_{as} , σ_{aos} and r_{aos}) and permanent environmental effects (σ^2_{po} , σ^2_{ps} , σ_{pos} and r_{pos}) of dairy traits for average temperature model.

Parameters	Daily milk yield (Kg)	Daily fat yield (g)	Daily Protein yield (g)	Daily fat+protein yield (g)	Daily fat content (%)	Daily Protein content (%)
σ^2_{ao}	264	490	226	1359	0.362	0.099
σ^2_{as}	39	75	24	176	0.045	0.011
$\sigma^2_{\mathrm{as}}/\sigma^2_{\mathrm{ao}}$	**0.148**	**0.153**	**0.104**	**0.130**	**0.125**	**0.114**
σ_{aos}	-63	-110	-49	-306	-0.026^{ns}	-0.007^{ns}
r_{aos}	**-0.621**	**-0.574**	**-0.674**	**-0.626**	**-0.204**	**-0.198**
σ^2_{po}	284	519	269	1498	0.072	0.012
σ^2_{ps}	11	194	71	505	0.033	0.023
$\sigma^2_{\mathrm{ps}}/\sigma^2_{\mathrm{po}}$	**0.039**	**0.374**	**0.263**	**0.337**	**0.464**	**2.030**
σ_{pos}	-21^{ns}	-179	-50	-402	-0.031	-0.003^{ns}
r_{pos}	**-0.376**	**-0.564**	**-0.360**	**-0.462**	**-0.637**	**-0.185**

^{ns} not significant.

Estimated heritability of daily milk and milk components yields and contents of milk components throughout the THI, Tmax and Tave ranges of values, are shown in Figure 3.3. The patterns of changes of the estimated heritability in all three cases are similar and the estimates are within the range of those reported for other Spanish breeds (Menéndez-Buxadera *et al.,* 2012). The h^2 of contents of milk components are higher than those of milk and milk components yields, except for milk yield at low values of the climatic variables. All h^2 decrease when the climatic variable increases. The decrease is steady and higher for yields than for contents. It is moderate for both THI and Tmax and it is higher for Tave for all traits.

Figures 3.4 and 4.4 show the estimates of the genetic (r_a) and permanent environmental correlations (r_p) between first and different points in the scales of THI, Tmax and Tave values, respectively.

Genetic correlation between first point and different points in the scales of THI, Tmax and Tave values decreases for all dairy traits as heat stress rises, reaching values below 0.80 for THI and Tmax. They get to drop below 0.60 for milk content traits in the cases of THI and Tmax and for all traits studied in Tave model. According to Robertson (1959) a genetic correlation below 0.80 is considered as an indication of the existence of an important effect of G×E interactions. However, Mulder (2007) consider G×E relevant when genetic correlations between the traits expressed at different environment is below 0.60, which is a threshold that has been reached for all traits studied in the Tave model. It can be concluded, that the values of these traits at different climatic conditions can be considered as partially genetically different traits.

In contrary to what Menéndez-Buxadera *et al.* (2012) reported, permanent environmental correlation between subsequent points in the scales of THI, Tmax and Tave for all dairy traits showed an earlier inflexion point and a faster decrease than genetic correlation. This means that not only we are dealing with important G×E interaction but, furthermore, repeatability of the phenotypic expressions of these traits under different climatic conditions is also different.

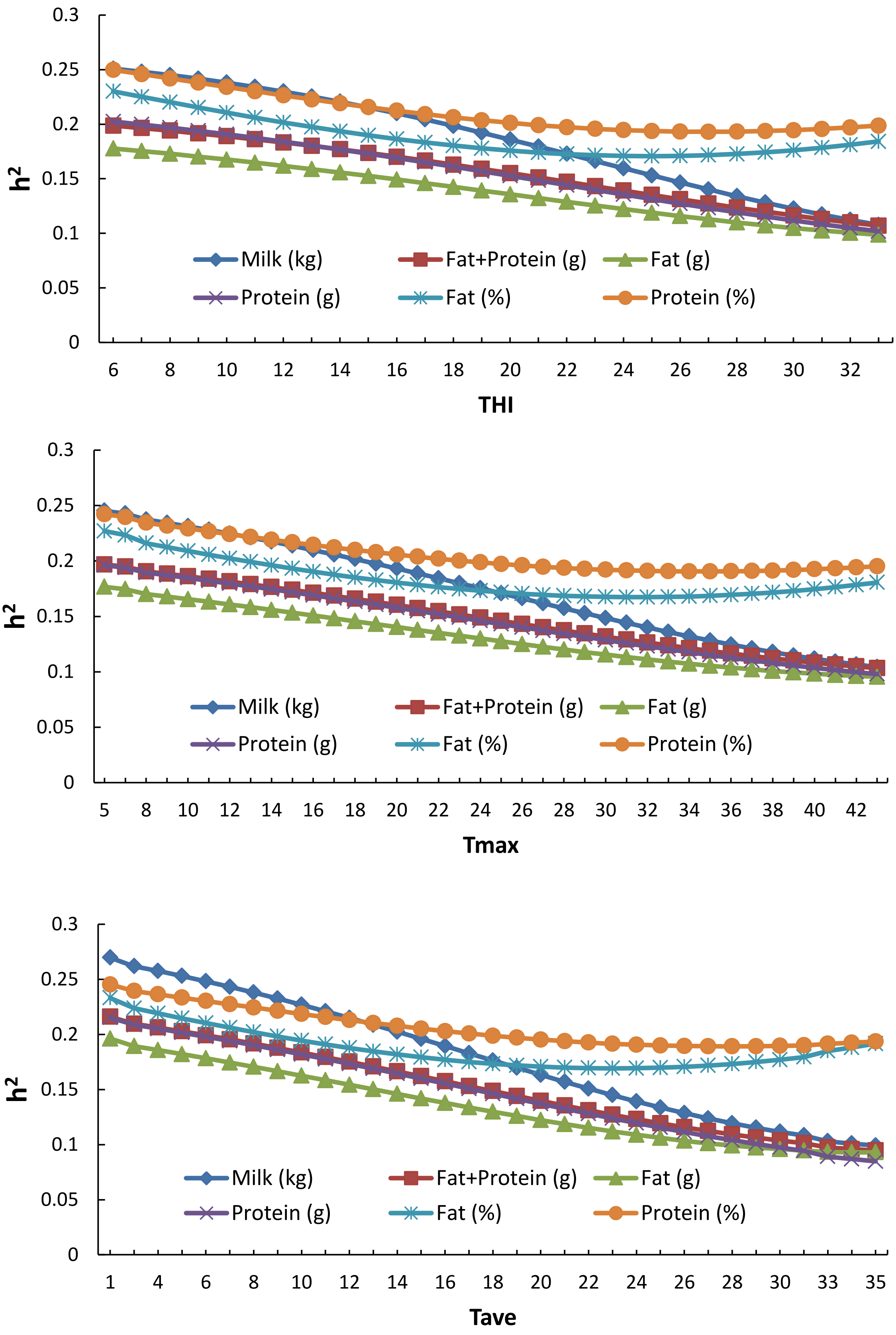


Figure 3. 3. Heritability of daily milk and milk components yields and daily contents of milk components through the scale of values of THI, maximum (Tmax) and average (Tave) temperatures.

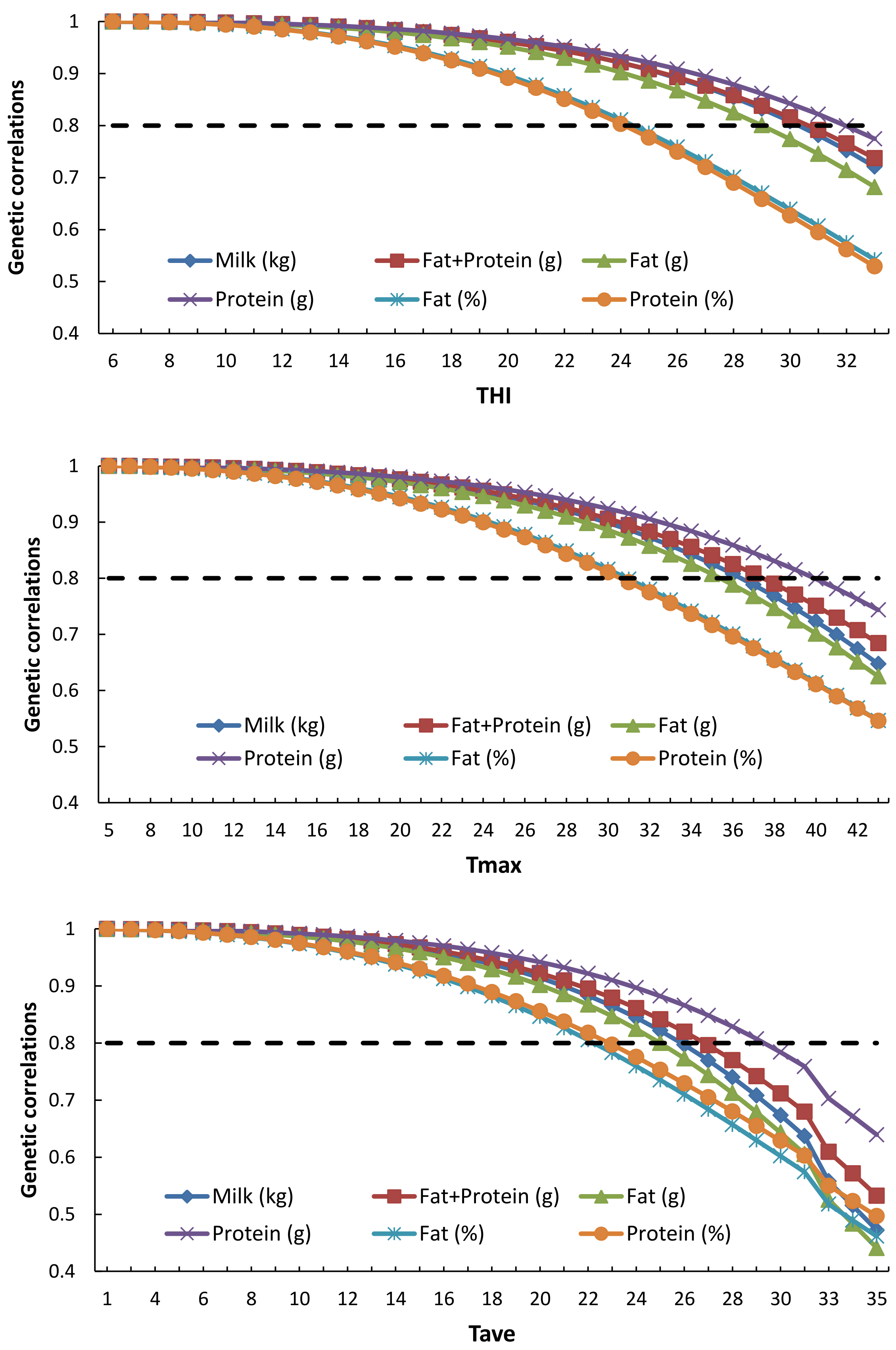


Figure 3. 4. Genetic correlations of values of daily milk and milk components yields and daily contents of milk components between first and different points through the scale of values of THI, maximum (Tmax) and average (Tave) temperatures.

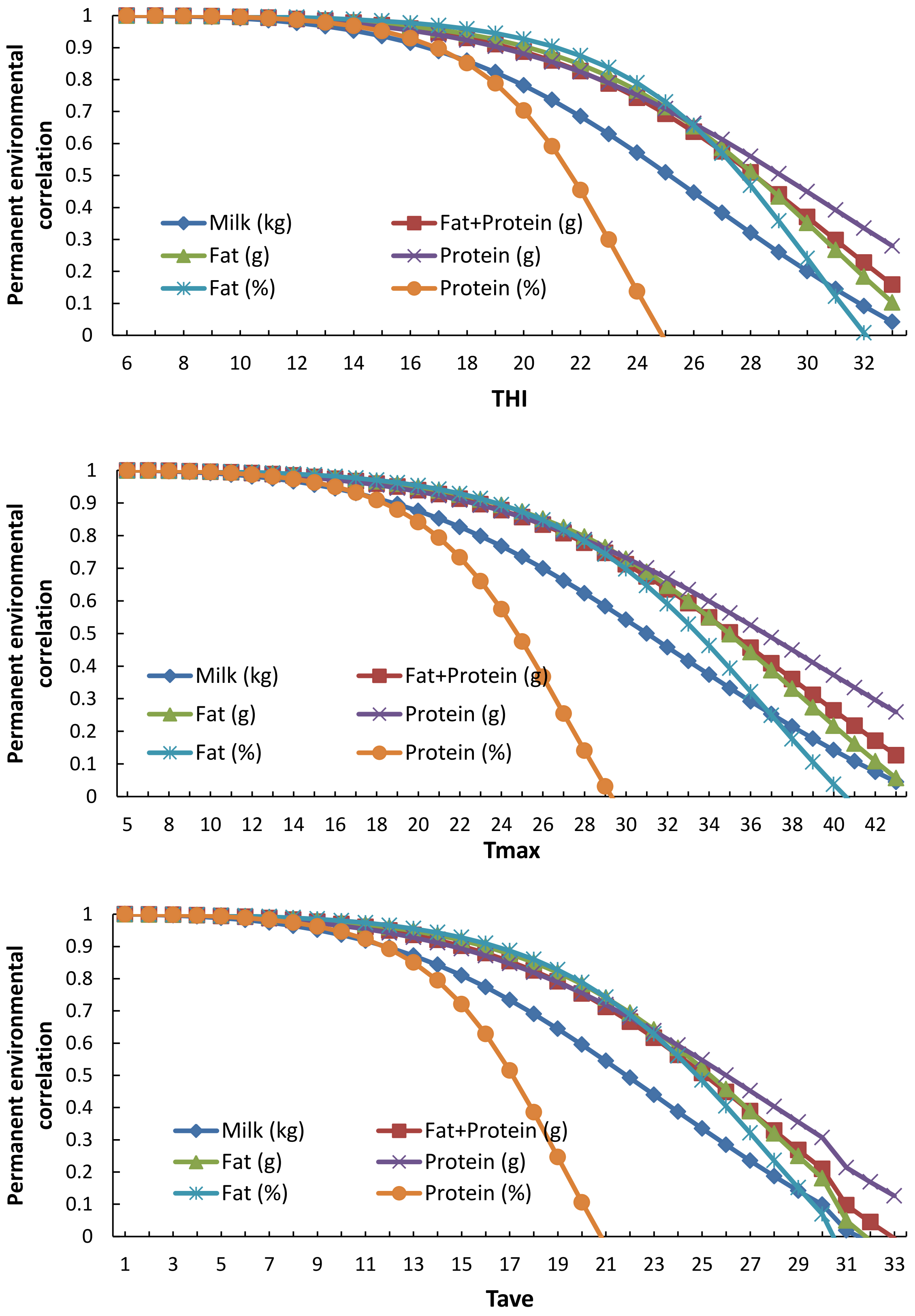


Figure 3. 5. Permanent environmental correlations of values of daily milk and milk components yields and daily contents of milk components between first and different points through the scale of values of THI, maximum (Tmax) and average (Tave) temperatures.

The random regression procedure used here allows for the estimation of the breeding value of each animal at any point of the environmental scale (THI, Tmax or Tave). A test of the variation of EBV of different animals through the scale of THI values was carried out for daily fat plus protein yield. The best 500 and the worst 500 animals for their EBVs, computed at the inflection point of the response for daily fat plus protein yield (THI=31), were selected. These animals showed different types of response to increasing THI values, as shown in Figure 3.6. Both groups of animals show a large range of EBV which makes them indistinguishable when there is not heat stress (below THI=31). According to their responses, animals could be categorized into the three types described by Menéndez-Buxadera *et al.* (2012): (i) Robust animals, which show a stable performance throughout the THI trajectory (with an average intercept and an average slope); (ii) Tolerant animals, which show a low genetic level (low intercept) and a high genetic capability to adapt to climatic stress (positive slope); and (iii) Non-tolerant animals, which manifest a high genetic level (high intercept) and very low capability to adapt to stressful climate conditions (negative slope).

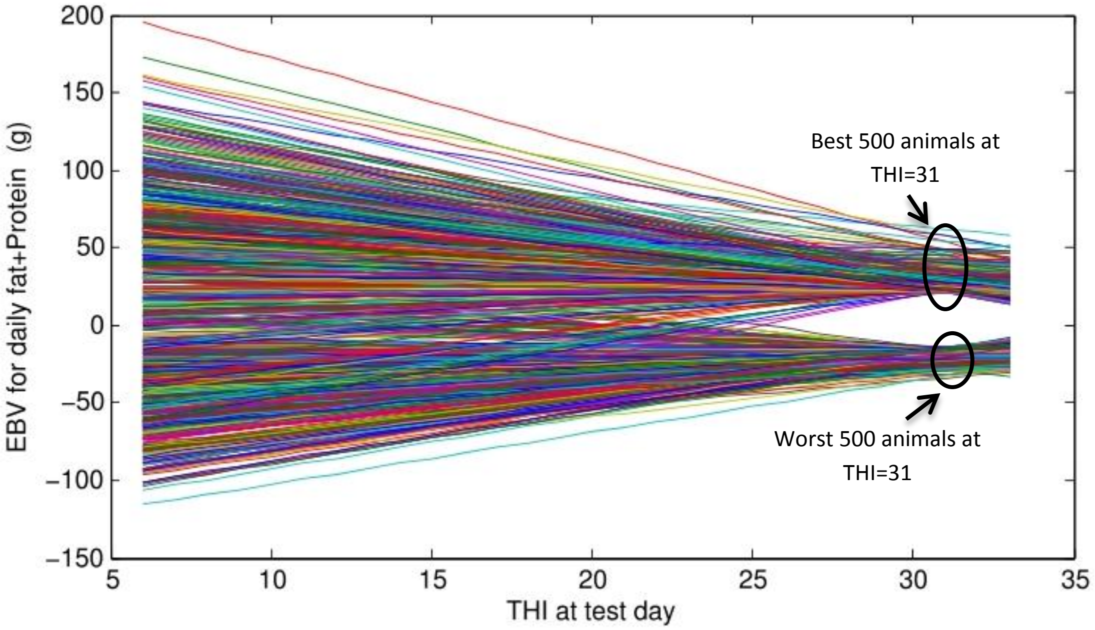


Figure 3. 6. Comparison of the change of the estimated breeding values (EBV) through the scale of values of an index of maximum temperature and relative humidity (THI) of the best 500 and the worst 500 animals selected by their EBV at THI=31 .

3. 5. Conclusions

The same trends of the response of dairy traits to heat stress were observed for all three climatic variables studied (TH, maximum and average temperature), being higher the genetic correlation between the intercept and the slope of the response to THI. The negative genetic correlation between the intercept and the slope, together with the patterns of genetic correlations between first point and different points in the scales of the climatic variables, provide an evidence that selection for better milk performance will reduce heat stress tolerance. Genetic variation for heat stress tolerance, and the differences between animals for their patterns of variation of their EBV through the trajectory of values of the climatic variables, could be used to select animals according to their response to heat stress (robust, tolerant and non-tolerant).

3. 6. References

BOE. 2005. REAL DECRETO 368/2005, de 8 de abril, por el que se regula el control oficial del rendimiento lechero para la evaluación genética en las especies bovina, ovina y caprina. Ministerio de Agricultura, Pesca y Alimentación. 97: 13918-13937.

Bohmanova, J.; Misztal, I. and Colet, J.B. 2007. Temperature– humidity indices as indicators of milk production losses due to heat stress. J. Dairy Sci., 90: 1947–1956.

Carabaño, M.J.; Ramón, M.; Abo-Shady, H.M.; Pérez-Guzmán, M.D.; Serrano, M.; Díaz, C.; Molina, A.; Menéndez-Buxadera, A.; Bahchaga, K.; Pérez-Cabal, M.A. and Serradilla, J.M. 2013. Estrés térmico en razas autóctonas de rumiantes lecheros. Proceedings of the XV Jornadas sobre Producción Animal. Asociación Interprofesional para el Desarrollo Agrario (AIDA), XV(2): 451-452.

De Jong, G. 1990. Quantitative genetics of reaction norms. J. Evol. Biol., 3: 447–468.

Finocchiaro, R.; Van Kaam, J.B.C.H.M.; Portolano, B. and Misztal, I. 2005. Effect of heat stress on production of Mediterranean dairy sheep. J. Dairy Sci., 88: 1855–1864.

Gilmour, A.R.; Cullis, B.R.; Welham, S.J. and Thompson, R. 2000. ASREML Reference Manual. NSW Agric. Biom. Bull. NSW Agriculture, Locked Bag, Orange, NSW 2800, Australia, pp. 398.

Jamrozik, J.L. and Schaeffer, L.R. 1997. Estimates of genetic parameters for a test day model with random regression for production of first lactation. J. Dairy Sci., 80: 762–770.

Johnson, H.D.; Ragsdale, A.C.; Berry, I.L. and Shanklin, M.D. 1962. Effect of various temperature humidity combinations on milk production of Holstein cattle. Missouri Agric. Exp. Sta. Res. Bull. 791:1–39.

Kelly, C.F. and Bond, T.E. 1971. Bioclimatic factors and their measurement: A guide to environmental research on animals. National Academy of Sciences, Washington, DC, pp. 71-92.

Kolmodin, R. and Bijma, P. 2004. Response to mass selection when the genotype by environment interaction is modelled as a linear reaction norm. Genet. Sel. Evol., 36: 435–454.

Menéndez-Buxadera, A.; Molina, A.; Arrebola, F.; Clemente, I. and Serradilla, J.M. 2012. Genetic variation of adaptation to heat stress in two Spanish dairy goat breeds. J. Anim. Breed. Genet., 129: 306-315.

Mulder, H.A. 2007. Methods to optimize livestock breeding programs with genotype by environment interaction and genetic heterogeneity of environmental variance. PhD thesis: Wageningen University (The Netherlands), pp. 208.

Ravagnolo, O. and Misztal, I. 2000. Genetic component of heat stress in dairy cattle, parameter estimation. J. Dairy Sci., 83: 2126–2130.

Ravagnolo, O. and Misztal, I. 2002. Studies on genetics of heat tolerance in dairy cattle with reduced weather information via cluster analysis. J. Dairy Sci., 85: 1586–1589.

Robertson, A. 1959. The sampling variance of the genetic correlation coefficient. Biometrics, 15: 469–485.

SAS. 2009. SAS User's Guide: Statistics. Version 9.2. SAS Inst. Inc., Cary, NC., USA. Pp. 7869.

Silanikove, N. 2000. Effects of heat stress on the welfare of extensively managed domestic ruminants. Livest. Prod. Sci., 67: 1–18.

General discussion

Generally, it is well known that heat stress affects behavior, well-being and productivity of dairy cows (Kadzere *et al.*, 2002; West, 2003). Although sheep and goats are thought to be more resistant species among the domestic ruminants to extreme climatic conditions, especially to high ambient temperatures (Oseni and Bebe, 2010; Sevi and Caroprese, 2012), there are evidences that heat stress has also an undesirable effect on the dairy performances, as Finocchiaro *et al.* (2005) and Marai *et al.* (2007) reported recently for sheep and Menéndez-Buxadera *et al.* (2012a) for goats. The latter authors reported the first indication of the negative effect of heat stress on dairy performance in two Spanish breeds of goats. Our results confirm this effect in another local breed, both at the phenotypic and at the genotypic level.

Contrary to what has been reported in other works (Dikmen and Hansen, 2009), in this study THI was not found to be the best indicator to explain the change in dairy traits caused by the climatic effect. This result could be explained by the pattern of variation through the year of temperature and humidity in the region where the animals of this breed are raised. Summer in this region, when heat stress is strong, is characterized by very high temperatures with very low humidity and for that combination of temperature and humidity THI values are not very high. Another reason that could explain this result is that average temperature has been defined in this work as the mean of maximum and minimum daily temperatures, while the THI was calculated using maximum temperature as suggested by Finocchiaro *et al.*(2005).This explanation is in agreement with that of Igono *et al.* (1992), who stated that the severity of heat stress depends on the diurnal fluctuations of the ambient temperature, as they observed that when temperature drops at night below 21°C during 3 to 6 hours, animals have sufficient opportunity to lose all heat accumulated on previous day. Moreover, Carabaño *et al.* (2013) found recently that models based on average temperatures explained better than models based on THI the changes taking place in dairy traits of Spanish breeds of sheep and goats under hot summer conditions.

Production of Florida dairy goats is most affected by the climatic conditions of the day of production or one day before. Similarly, Finocchiaro *et al.* (2005) reported that the decrease in ewes dairy yield per unit of THI was most correlated to the THI registered the day before milk recording. On the contrary, West *et al.* (2003) mentioned that during hot weather, the average THI registered two days earlier had the greatest effect on cow milk yield. Herbut and Angrecka (2012) recorded a decrease in milk production 4 days after starting to register high temperatures.

The analyses carried out in this work showed that, within the range of temperatures registered in the area where Florida goats are raised, the positive coefficients of regression of climatic variables on milk yield indicate that these goats seem not to affected by heat stress, being more sensitive to cold than to warm temperatures. This observation coincides with farmer's empirical knowledge. In this same context, Baccari Júnior *et al.* (1996) reported that Saanen goats did not show any effect on milk yield when exposed to heat stress for 14 days. However, when a genetic analysis has been carried out, a negative correlation has been found between the genetic intercept and the slope, as well as between subsequent points in the scales of THI, maximum and average temperatures recorded on milk test day. Similarly, Finocchiaro *et al.* (2005) registered a negative genetic effect of heat stress on sheep milk yield.

Both phenotypic and genotypic analysis of dairy traits of Florida goats demonstrated that fat and protein yields and contents were negatively affected by heat stress. Similar results have been reported for dairy cattle (Bouraoui *et al.,* 2002; Gantner *et al.,* 2011), dairy sheep (Finocchiaro *et al.,* 2005; Menéndez-Buxadera *et al.*, 2012b)and other breeds of dairy goats (Menéndez-Buxadera *et al.,* 2012a). Milk contents rapidly declined when temperatures increase. However, the decline of yields of fat and protein is of a lesser magnitude and slower than that of contents. This could be the consequence of the formerly described increase of milk yield when temperature rises combine with the negative correlation between milk yield and protein and fat contents. On the contrary, Finocchiaro *et al.* (2005) founded that fat and protein contents were unaffected by heat stress in dairy sheep. Generally, the slopes of the regressions between the traits and the climatic variables were lower for protein content than for fat content. Similar result was found by Carabaño *et al.* (2013).

The effect of climate might vary from high yielding to low yielding animals. The first are expected to be more sensitive (Berman, 2005). Results from the phenotypic study of Florida data presented here support this theory, as climatic variables had a higher effect on high productive animals in respect to daily fat, protein and fat plus protein yields. The same was reported for these same traits in sheep (Carabaño *et al.*, 2013). While for low productive animals, it appears that different climatic variables have no significant effect on milk components (yields). When data from the warm and cold seasons were analyzed independently, generally, the average fat and protein yields and contents of warm season data were lower than those of the whole set of data from all goats, reflecting the effect of heat stress. This result is in agreement with those reported by Bouraoui *et al.* (2002) which indicated a decreased in milk protein percentage for Mediterranean dairy cows as a result of summer heat stress in respect to spring season.

Genetic improvement has been demonstrated to cause undesirable side effects such as low reproductive efficiency, increased susceptibility to disease and higher sensitivity to sudden environmental changes (Rauw *et al.*, 1998). Artificial selection to increase milk yield has been demonstrated to reduce heat tolerance in dairy cattle (Ravagnolo and Misztal 2000; Bohmanova *et al.*, 2007), dairy sheep (Finocchiaro *et al.*, 2005) and dairy goats (Menéndez-Buxadera *et al.*, 2012a). In this context, our results of a negative genetic correlation between the intercepts and the slopes of the Legendre polynomials modeling the relation between the dairy traits and the climate variables, together with the patterns of genetic correlations between the first and all the other points in the scales of the climatic variables, provide an evidence that selection for better milk performance will reduce heat stress tolerance. Moreover, the genetic correlations between first point and subsequent points in the scales of climatic variables decrease for all dairy traits as heat stress rises, reaching values below 0.80 which, according to Robertson (1959) are considered as an indication of the existence of an important effect of G×E interaction. Then, Florida dairy traits measured at different climatic conditions can be considered as partially genetically different traits.

As the two groups of best and worst animals, according to their EBV at the threshold THI (=31) show a large range of EBV through the range of THI values, which makes them indistinguishable when there is not heat stress (below THI=31) but with animals of any of the two groups showing three different types of response to increasing THI values(robust, tolerant and non-tolerant to heat stress), it would be useful to select the animals according to these types of responses to get the most suitable animals to each specific climate conditions and production system, as it has been already suggested by Menéndez-Buxadera *et al.* (2012a).

References

Baccari Júnior, F.; Gonçalves, H.C.; Muniz, L.M.R.; Polastre, R. and Head, H.H. 1996. Milk production, serum concentrations of thyroxine and some physiological responses of Saanen-native goats during thermal stress. Veterinária e Zootecnia., 8: 9-14.

Berman, A.J. 2005. Estimates of heat stress relief needs for Holstein dairy cows. J. Anim. Sci., 83: 1377-1384.

Bohmanova, J.; Misztal, I. and Colet, J.B. 2007. Temperature– humidity indices as indicators of milk production losses due to heat stress. J. Dairy Sci., 90: 1947–1956.

Bouraoui, R.; Lahmar, M.; Majdoub, A.; Djemali, M. and Belyea, R. 2002. The relationship of temperature- humidity index with milk production of dairy cows in a Mediterranean climate. Anim. Res., 51: 479-491.

Carabaño, M.J.; Ramón, M.; Abo-Shady, H.M.; Pérez-Guzmán, M.D.; Serrano, M.; Díaz, C.; Molina, A.; Menéndez-Buxadera, A.; Bahchaga, K.; Pérez-Cabal, M.A. and Serradilla, J.M. 2013. Estrés térmico en razas autóctonas de rumiantes lecheros. Proceedings of the XV Jornadas sobre Producción Animal. Asociación Interprofesional para el Desarrollo Agrario (AIDA), XV(2): 451-452.

Dikmen, S. and Hansen, P.J. 2009. Is the temperature-humidity index the best indicator of heat stress in lactating dairy cows in a subtropical environment? J. Dairy Sci., 92: 109–116.

Finocchiaro, R.; Van Kaam, J.B.C.H.M.; Portolano, B. and Misztal, I. 2005. Effect of heat stress on production of Mediterranean dairy sheep. J. Dairy Sci., 88: 1855–1864.

Gantner, V.; Mijić, P.; Kuterovac, K.; Solić, D. and Gantner, R. 2011. Temperature-humidity index values and their significance on the daily production of dairy cattle. Daily production of dairy cattle, Mljekarstvo, 61(1): 56-63.

Herbut, P. and Angrecka, S. 2012. Forming of temperature-humidity index (THI) and milk production of cows in the free-stall barn during the period of summer heat. Animal Science Papers and Reports, 30(4): 363-372.

Igono, M.O.; Bjotvet, G. and Sanford-Crane, H.T. 1992. Environmental profile and critical temperature effects on milk production of Holstein cows in desert climate. Int. J. Biometeorol., 36: 77–87.

Kadzere, C.T.; Murphy, M.R.; Silanikove, N. and Maltz, E. 2002. Heat stress in lactating dairy cows: a review. Livest. Prod. Sci., 77: 59-91.

Marai, I.F.M.; El-Darawany, A.A.; Fadiel, A. and Abdel-Hafez, M.A.M. 2007. Physiological traits as affected by heat stress in sheep: a review. Small Rumin. Res., 71: 1–12.

Menéndez-Buxadera, A.; Molina, A.; Arrebola, F.; Clemente, I. and Serradilla, J.M. 2012a. Genetic variation of adaptation to heat stress in two Spanish dairy goat breeds. J. Anim. Breed. Genet., 129: 306-315.

Menéndez-Buxadera, A.; Castro, J.A.; Medina, C.; Osorio, J.; Torres, R.; Serradilla, J.M. and Molina, A. 2012b. Estudio preliminar del efecto del estrés térmico en la producción lechera de la raza Merina de Grazalema. MG-FEAGAS, 37: 131-141.

Oseni, S. and Bebe, O. 2010. Climate change, genetics of adaptation and livestock production in low-input systems. 2nd International Conference: Climate, Sustainability and Development in Semi-arid Regions. Fortaleza - Ceará, Brazil, pp. 12.

Rauw, W.M.; Kanis, E.; Noordhuizen-Stassen, E.N. and Grommers, F.J. 1998. Undesirable side effects of selection for high production efficiency in farm animals: a review. Livest. Prod. Sci., 56: 15–33.

Ravagnolo, O. and Misztal, I. 2000. Genetic components of heat stress in dairy cattle, Parameter estimation. J. Dairy Sci., 83: 2126–2130.

Robertson, A. 1959. The sampling variance of the genetic correlation coefficient. Biometrics, 15: 469–485.

Sevi, A. and Caroprese, M. 2012. Impact of heat stress on milk production, immunity and udder health in sheep: A critical review. Small Rum. Res., 107: 1–7.

West, J.W. 2003. Effects of heat-stress on production in dairy cattle. J. Dairy Sci., 86: 2131-2144.

West, J.W.; Mullinix, B.G. and Bernard, J.K. 2003. Effects of Hot, Humid Weather on Milk Temperature, Dry Matter Intake and Milk Yield of Lactating Dairy Cows. J. Dairy Sci., 86: 232–242.