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Crossbred Dairy Cattle is the Answer to Improve Environment Dependent Productive and Physiological Responses – A Review

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ABSTRACT

Heat stress has severe effects in organisms. Dairy cattle is susceptible to suffer behavioral, physiological and reproductive damages due heat stress. Breeding searching for tolerant heat stress genes and their incorporation in crossbreeding programs has gained interest in dairy cattlemen concerned by the global warming and greenhouse effect in the environment. This review shows and update of the crossbreeding in dairy cattle in both hemispheres. Here, is reviewed the effect of heat stress on dairy cattle; the mechanism of autoregulation; the benefits of the heterosis in crossbreeding cattle by hybridization; the body condition score in crossbred dairy cattle; the yields in crossbreds; here is also discussed that even when there have been many crossbreeding in dairy cattle, but when the producer choose a system crossbreeding in dairy cows always mostly contemplate only body weight, body condition score, dry matter intake, and feed efficiency. Is suggested to contemplate other traits like genetic potential, lactation (305 d), lactation number, fertility rate, and economic impact to observe clarity the potential of each crossbred in dairy cattle in the future.

INTRODUCTION

For many years, the superiority for milk yield in Holstein breed cows has limited the use of other breeds or crossbreeding in dairy farms worldwide. In the USA, fewer than 7% of dairy herds are other than purebred or grade Holsteins (McAllister, 2002; Nehring *et al*., 2017). However, over the past few years dairy producers have shown more interest in crossbreeding programs for dairy cattle, especially in warm climate regions. Through classical genetic improvement tools a heat tolerant gene can be introduced into a less heat tolerant breed helping cattle to better adapt to warmer environmental temperatures.

Holstein cows have outstanding production when environment temperatures ranges between 5 and 25°C and temperature-humidity index (THI) does not exceed 72 units which is considered the thermal comfort zone for dairy cows (McDowell, 1972; Akyuz *et al*., 2010). However, in areas subjected to warm climates Holstein cows do not fully express their potential for milk yield and have their reproductive proficiency compromised (Dikmen *et al*., 2009; West, 2003; De Rensis and Scaramuzzi, 2003). Cows that calve during winter months produce more milk in 305-day lactations than cows calving during hot summer months (McDaniel *et al*., 1967). In a study in Israel during summer Holstein cows decrease milk yield, 8 % and conception rate 70 % regarding winter (Flamenbaum and Galon, 2010). In agree, Folman *et al*. (1979) found only about an 8% decline in milk yield for summer conditions when the mean afternoon temperature was 39.8 °C compared with winter conditions. Studies carried in climatic chambers, described a decrease in milk yield of 14% in early lactating dairy cows (Lacetera *et al*., 1996) kept under heat stress conditions. Under Mediterranean climatic conditions, summer calvers produce less milk per lactation than winter calvers (Barash *et al*., 1996). In Po Valley, northern Italy, Speroni *et al*. (2006) found 16% less milk yield after the start of the hot period regarding before the star of the hot period in multiparous dairy cows under milking parlor system. Following, diverse authors have shown their preoccupation respect to heat stress topic on milk yield in different parts of the world such as Missouri, Arizona, U.S., Israel, México, *etc*. (Igono *et al*., 1987, 1992; Her *et al*., 1988; Flamenbaum *et al*.,

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1995; Correa *et al.*, 2002; Avendaño *et al.*, 2006, 2010; Adin *et al.*, 2009). Also, St-Pierre *et al.* (2003) reported that heat stress greatly affected economic loss by the US dairy industry and that estimated losses ranged from $897 to $1,500 million, annually. Several strategies have been suggested to minimize the negative effect of heat stress in dairy cows, including facilities design, cooling systems, feeding and breeding strategies and genetic management (Armstrong, 1994; West, 1999; Berma, 2008).

A recent report evaluating the breed composition of the US dairy cattle identified an increased percentage of crossbred dairy herds in US from 0.4 % for cows born in 1990 to 0.7 % in 2000 and 1.6% in 2005 (Powell *et al.*, 2008). More recently, it has been estimated the US dairy cattle population of 9.2 million of dairy cows (USDA, 2009) in which 3.3% correspond to the crossbred and 90.1% to Holstein cows. These crossbred cows in the US are responsible for 2.7 million kg of milk and 102,000 kg of milk fat. In New Zealand, the proportion of crossbred dairy cows is higher than in the US. In the New Zealand 2006/2007 season dairy cow population accounted with 3.92 million of dairy cows (LIC, 2007) in which crossbred represented 31.6% mainly formed by Jersey x Holstein cross. These crossbred cows were responsible for 15.1 billion Kg of milk and 750 million Kg of milk fat and 566 million Kg of milk protein during that season. Differently than US and New Zealand, other places in Africa and Asia uses *Bos taurus* x *Bos indicus* crossbreds for dairy propose. In Thailand, more than 95% of the dairy herd is crossbred using Holstein and Sahiwal or Thai native breeds (Boonkum *et al.*, 2011). The benefit of this crossbreeding strategy is the introduction of heat tolerant and diseases resistant gen from Sahiwal or Thai native into a less heat tolerant and less disease resistant breed such as Holstein (Reodecha *et al.*, 2002; Chanvijit *et al.*, 2005). The advantage of these crossbreeding strategies is due the hybrid vigor (heterosis) observed on the hybrid offspring (Hill *et al.*, 1983; Lopez-Villalobos *et al.*, 2000).

Therefore, the objective of this review is to describe the main effects of the environmental heat stress on productive and physiological responses crossbred dairy cows.

EFFECT OF HEAT STRESS ON DAIRY CATTLE

Heat stress is a term that describes the increase of several environment conditions such as: humidity, air temperature, radiation, and air movement (Jordan, 2003). Thus, the heat stress appears when any combination of these environmental conditions causes discomfort in the animal due to inefficiency heat loss, this produces negative effects on the productive and reproductive efficiency of the dairy cattle (Armstrong, 1994; McManus *et al.*, 2011). Heat stress compromises oocyte growth in cows by altering progesterone, the secretion of luteinizing hormone and follicle-stimulating hormone and dynamics during the oestrus cycle (Ronchi *et al.*, 2001; Hernández *et al.*, 2011). Also, a drop can occur in summer of about a 20–27% in conception rates (Chebel *et al.*, 2004; Lucy, 2002; Calderón *et al.*, 2012) or a decrease in 90-day non-return rate to the first service in lactating dairy cows (Al-Katanani *et al.*, 1999; Das *et al.*, 2016; Ali *et al.*, 2018).

On the other hand, Johnson (1976) attributed that the milk yield variation was due to climatic factors is among 3-10%. In addition, dairy cows in lactation produce greater amount of metabolic heat, this combined with the heat generated by atmosphere result in the increase and gain from heat corporal (Fuquay, 1981; Krishnan *et al.*, 2017). The heat increment for feeding in cattle is high (35-70% of metabolisable energy), depending on the balance of nutrients. Heat increment is non-useful energy and, during heat stress, must be dissipated (Polsky and von Keyserlingk, 2017; Grandl *et al.*, 2018). As environmental temperature increases, animals require extra energy to dissipate the heat load (Al-Dawood, 2017). Reduction of fiber intake, particularly with a minimum fall in metabolizable energy, may lower the heat increment sufficiently to act as a partial protection against forecast high heat stress (Fuquay, 1981; Al-Dawood, 2017). As the result, the higher threshold in the Thai crossbred population might due to the combinations of heat-tolerance genes from *Bos indicus* and the lower production. Generally, Thai cattle are rarely fed to their genetic potential because of the low quality of tropical roughages (Boonkum *et al.*, 2011). The best recognized effect of heat stress is an adaptive depression of metabolic rate associated with reduced appetite (Silanikove, 2000). Heat stress causes the rostral cooling center of the hypothalamus to stimulate the medial satiety center which inhibits the lateral appetite center and consequently lowers milk yield (Kadzere *et al.*, 2002). The arterial plasma volatile fatty acids they are in the form of acetate. Animals under heat stress conditions the plasma acetate percent is high (69% to 77%) this would be explainable in the light of the high energy and substrate demands for milk synthesis, because acetate is the major energy source of normal fed ruminants (Chaiyabutr *et al.*, 2008). In addition, acetate is involved in mammary gland metabolism in either de novo synthesis of short and medium-chain milk fatty acids or generation of ATP and NADPH. On the other hand, the high values of concentrations of arterial plasma β-hydroxybutyrate on animals under heat stress would be consistent with an increase in oxidation of free fatty acids (Bauman *et al*., 1988; Al-Dawood, 2017). A greater energy requirement due to panting of animals during heat stress, resulting in increased hepatic ketogenesis due to greater mobilization of fat reserves, might be apparent under high temperatures (Collier *et al*., 2017a). A simple approach to quantify heat stress is the THI which is estimated by combining environmental temperature and relative humidity (*i.e.* THI = [0.81 x average temperature] + relative humidity [average temperature – 14.4] + 46.4; Hahn, 1999). Using this index, heat stress in dairy cattle starts at 72 units (Armstrong, 1994). Environmental effects on milk yield are difficult to determine due to can be affected by other factors such as management nutrition which can or not be ligature to factors related to the environment (Fuquay, 1981). However, currently studies on environmental impacts of milk were assessment (De Vries and de Boer, 2010). In a study, cows were fed diets of 16%, 17.9%, 19.4% and 21.2% acid detergent fiber during warm (THI between 64 and 77) and hot weather conditions (THI between 72 and 84) (Table I). However, Thatcher *et al.* (1994) has divulged fat and milk yield less like result by high temperatures. Heat stress has effect negatives on the secretory function of the udder (Silanikove, 1992). In addition, when dairy cows be are on THI by 83, the milk yield can fall 53%, and total energy output fall 48% (Anzures-Olvera *et al*., 2015). Also, percentage of fat, protein and lactose in milk decrease 19, 13, and 9%, respectively (Joksimović-Todorović *et al*., 2011). In order to improve the milk yield it is major lower levels of hyperthermia by environmental manipulation. Several studies have shown different cooling strategies to decrease heat stress effects on milk yield in dairy cattle (Table II).

Autoregulation mechanism on environmental

Physiological variables on crossbred dairy cattle are shown in Table III. Heat flow occurs through processes dependent on surrounding temperature (sensible heat loss; *i.e.* conduction, convection, radiation) and humidity (latent heat loss; evaporation through sweating and panting) (Hansen, 2004; Allen *et al*., 2015; Chand *et al*., 2017). The rectal temperature (RT) and respiration rate (RR) are excellent indicators to predict the heat stress presence in the dairy cattle (Collier *et al*., 2017b). Fabris *et al.* (2017) reported that cows increase RT and RR from 77 units of THI. Under heat stress condition the RR can increase 64% more than normal (20 breath/min) in thermoneutral zone (Arias *et al*., 2018). Berman *et al.* (1985) found that the respiratory frequency started rising above 50–60 breaths / min at ambient temperatures higher than 25 °C).

Table I.- Effect of heat stress on milk yield (kg day^{-1}) and % milk fat of cows fed diets differing in acid detergent fiber (ADF) concentrations.

	Milk yield (kg day^{-1})		**Milk fat (%)**	
% ADF of diet	**Warm temp.[a,c]**	**Hot temp.[b,d]**	**Warm temp.[a]**	**Hot temp.[b,c]**
16.00	32.30	24.60	3.24	3.21
17.90	32.60	25.80	3.49	3.28
19.40	31.40	26.40	3.58	3.50
21.20	28.90	22.70	3.62	3,69

a, Minimum and maximum THI was 64 and 77, respectively; b, Minimum and maximum THI was 72 and 84, respectively; c, Linear effect; d, Quadratic effect. Source, West *et al.* (1999).

Table II.- Strategies of cooling and THI on the milk yield of dairy cattle during summer.

Location	**Treatment and milk yield (kg/d)**		**THI (Max)**	**Cooling time (h/d)**	**Reference**
	NC	**C**			
Missouri, USA	23.00	25.00*	76.00	24.00¤	Igono *et al.* (1987)
Israel	32.10	35.00*	87.60	4.50	Her *et al.* (1988)
Arizona, USA	23.00	32.00*	79.00	11.00	Igono *et al.* (1992)
Beit-Dagan, Israel	34.00	35.00	78.00	11.00¥	Flamenbaum *et al.* (1995)
Mexicali, Mex	27.00	31.00*	89.00	8.00	Correa *et al.* (2002)
Mexicali, Mex	20.20	22.20*	79.00	3.00	Avendaño *et al.* (2006)
Mexicali, Mex	19.10[1]	21.12*	91.30	3.00	Avendaño *et al.* (2010)
Mexicali, Mex	17.43	18.70*	83	4	Avendaño *et al.* (2012)
Mexicali, Mex	16.16	16.12	83	4	Hernández *et al.* (2011)
Moshav Timmorim, Israel	39.30	41.40*	77.40	4.00	Adin *et al*., 2009
Kingdom, Saudi Arabia	52.28≠	52.20∞	80	13-14	Ortiz *et al.* (2015)
Pirassununga, SP, Brazil	18	22	78	24	Titto *et al.* (2013)
Buckeye, Arizona	29.6	31.3	80	2.25	Anderson *et al.* (2013)

*P<0.05; NC, Control; C, Cooling; THI, temperature-humidity index.[1] Cooling by one hour, cooling system ignited if the environmental were greater to >27ºC; ¥, Cooling system ignited each 2 h during 30 min. ≠, Korral Kool system (Korral Kool Inc., Mesa, AZ); ∞, FlipFan system (Schafer Ventilation Equipment LLC, Sauk Rapids, MN).

Table III.- Physiological variables on crossbred dairy cattle differences.

Crossbred group	Rectal temperature (°C)	Respiration rate (breaths/min)	Body condition score	Reference
Jersey x Holstein	-	-	2.90 ± 0.03^a	Heins *et al.* (2008a)
Holstein	-	-	2.76 ± 0.04^b	
Jersey x Holstein	-	-	2.80 ± 0.03^a	Heins *et al.* (2008b)
Holstein	-	-	2.71 ± 0.03^b	
Brahman x Holstein	39.86 ± 0.48	85.16 ± 1.37	-	Khongdee *et al.* (2010)
Thai x Holstein	41.21 ± 0.28	86.87 ± 0.12	-	Khongdee *et al.* (2006)
Jersey x Holstein	-	-	4.62 ± 0.01^a	Auldist *et al.* (2007)
Holstein			4.54 ± 0.01^b	
Red Shindi x Holstein	39.37 ± 0.7	73 ± 15.67	-	Chaiyabutr *et al.* (2008)
Cambodian native zebu × Holstein-Friesian	40.0 ± 1.0	-	-	Bun *et al.* (2018)
Zebu x Holstein	38.6 ± 0.75	55 ± 2.52	-	De Paula Xavier de Andrade *et al.* (2017)
Gyr x Holstein	≥ 39.3	≥ 36	3.5	Da Costa *et al.* (2015)
Gyr x Holstein	-	65 ± 5	-	Santos *et al.* (2017)

Means with different superscripts within a row are significantly different ($P < 0.05$).

On the other hand, it has been observed that RR can decrease after providing cold water (Golher *et al.*, 2015). The RT increase 0.7% more than normal (38.5 °C) (Igono *et al.*, 1992). It has been demonstrated that under heat stress conditions RT increases, then decreases the consumption of dry matter, cud process and food passage rate (Kamal *et al.*, 2016a, b). Consequently, milk production decreases, mainly in cows that have been exposed to high temperatures for at least 67 days (Ammer *et al.*, 2018). It appears that there are notable differences between breeds in their abilities to regulate RT: the mean rectal temperature is higher in *Bos taurus* than in *Bos indicus* cattle (Hansen, 2004) and, as a result, *B. taurus* cattle are more sensitive to heat stress than their *Bos indicus* counterparts (Hansen, 2007). An increase in the panting and sweating by dairy cows would be the normal mechanism by which animals dissipate heat load from their body to maintain thermoregulation in hot ambient conditions (Polsky and von Keyserlingk, 2017). In fact, during heat stress, evaporative heat loss via respiration rate can be greater for European breeds respect *Bos indicus* (Gaughan *et al*., 1999). Kibler and Brody (1950) showed that Jersey cows had much higher respiration rates than Holsteins, which they attributed to the Jersey cows better ability to dissipate heat compared to Holsteins. Then it is not to be surprised that Jersey x Holstein cows had lower vaginal temperatures during much of the day than Holstein or Jerseys suggests that thermotolerance is another trait controlled by heterosis (Dikmen *et al*., 2009). The hair coats of cattle of different breeds vary from fine and glossy to thick and woolly, and present a range of insulation values; this will affect heat exchange by convection and evaporation of sweat. Since year 50's we know that zebus had a higher sweating rate than European breeds (Kibler and Brody, 1952). It was not until ends 50's and beginning 60's when discovering that gland numbers in zebus is greater than British breeds (Ferguson and Dowling, 1955; Allen *et al*., 1962). In fact, studies have now been made to confirm that the rate of sweating is higher in *Bos indicus* (Gaughan *et al*., 1999). Blazquez *et al.* (1994) reported that increased blood flow to the skin is positively correlated to the sweating rate. Likewise, the direct relationship between the rate of skin sweating and the coat surface temperature (Silva and Maia, 2011). Jersey heifers showed a linear increase in sweating rate with increasing air and skin temperature, whereas the sweating rate of zebu heifers did not rise until skin temperature reached 35 °C and air temperature 30°C (Allen, 1962). In fact, sweating rate was greater for zebu cattle than european cattle (Hansen, 2004). Respiratory rate was also greater in the Jersey, indicating more reliance on respiratory evaporation. Sharma *et al.* (1983) showed that, within *Bos taurus* dairy cattle breeds, the Jersey was less sensitive to thermal stress than the Holstein-Friesian. Among heat-adapted cattle, the sweating rates of *Bos indicus* increase exponentially with rises in body temperature, but in *Bos taurus,* sweating rates tend to plateau after an initial increase (Finch *et al*., 1982). Schmidt-Nielsen (1964) reported that as the environmental temperature rose, *Bos taurus* cattle showed an appreciable increase in evaporation between 15 and 20 °C, with a maximum rate of evaporation being reached before 30 °C. On the contrary, Brahman cows (*Bos indicus*) had initially lower evaporation rates, but rapid evaporation rates occurred when temperatures were between 25 and 30

°C, and continued rising up to 40 °C. Cattle in temperate and tropical regions possess the same type of sweat glands, one to each hair follicle (Findlay and Yang, 1950). Cattle with shorter hair, hair of greater diameter and lighter coat color are more adapted to hot environments than those with longer hair coats and darker colors (Bernabucci *et al*., 2010). However, tropical breeds have a higher density of hair follicles (1698/ cm² for Zebu) than is the case in *Bos taurus* breeds (1064/ cm² for Shorthorn) (Dowling, 1955; McManus *et al*., 2014). The metabolic rate is greater in *Bos taurus* than *Bos indicus* cattle even 80-85% (Vercoe, 1970). Finch (1985) showed that under high heat stress, resistance to heat transfer in Brahman cattle continued to fall as the skin temperature approached the body core temperature, whereas in Shorthorn cattle there was an abrupt increase in resistance as the temperature differential reached 2 °C. As a consequence, heat storage rose rapidly in the Shorthorn.

HETEROSIS IN DAIRY CATTLE

Heterosis is the added increase in performance when animals are crossbred, and usually defined as the superiority of a first cross (F_1) over and above the mean of the two parental strains (Syrstad, 1985; Kelleher *et al*., 2017). Also, heterosis can be estimated indirectly from many different combinations of crosses, *e.g.* by comparing pure bred with F_1 or F_1 with F_2. In a study, McDowell (1982) showed different types of dairy performance traits to determine whether hybridization would produce cattle of improved adaptability and production (Table IV). Over the past few years dairy producers have shown more interest in crossbreeding programs for dairy cattle especially in warm climate regions. Often Canadian and United States dairy producers have a well standpoint about crossbred importance on this topic; they can have estimated sire genetic merit on a regional and national basis until 1995 because of the expectation that genotype x region interactions may be important to know what crossbred to choose and to use advisable in his dairy farm (Boettcher *et al*., 2003; Norman *et al*., 2005). Through classical genetic improvement tools a heat tolerant gene can be introduced into a less heat tolerant breed helping cattle to better adapt to warmer environmental temperatures. Crossbreeding programs are available for dairy cattle and it has been used as one of these strategies to improve resistance to thermal stress. The first publications on the performance of *Bos taurus* x *Bos indicus* crossbred cattle appeared more than 50 years ago (Syrstad, 1985). Diverse researches have been reported performance of crossbred dairy cows exposed to heat stress (Heins *et al*., 2006, 2008a, b; Khongdee *et al*., 2010; Boonkum *et al*., 2011). It is known that conventional crossbreeding between breeds of *Bos taurus* cattle and *Bos taurus* with *Bos indicus* cattle (F_1) has been a strategy to improve resistance to thermal stress; but always lowers milk yields in the F_1 generation compared to the *Bos taurus* purebred dairy cow. In agreement, Bohmanova *et al*. (2005) found bulls that transmit a high tolerance to heat stress have daughters with higher pregnancy rates and a longer productive life; but lower milk yields. In addition, although these results are the answer to choose any milk crossbred, this crossbred topic could be but complicated that it seems, something difficult to explain. Because in practical terms several studies show different results on crossbred dairy cattle, whereas others factor like location, clime and year are variables very important to consider (Table V).

Table IV.- Range in heterosis values for different types of dairy performance traits.

Trait	Heterosis (%)
Yields	5.0–6.6
Viability (livability)	3.7–4.6
Growth	3.2–5.7
Reproduction	0.8–5.0

Source, McDowell, (1982).

BODY CONDITION SCORE IN CROSSBRED

Studies indicate that the body condition score (BCS) is greater or equal between Jersey and Holstein purebred cows (Washburn *et al*., 2002; Rastani *et al*., 2001). For this reason other studies have shown that BCS is highly difference between Holstein and Jersey x Holstein having advantage crossbred on purebred cows (Heins *et al*., 2008a, b; Auldist *et al*., 2007). This difference is related with nutrition of low quality, *e.g.* when the pasturing like only source of nutrition is provided. It is very important provide energy supplementation in these cases. If not, consecutively they would have BCS relatively low. Also, is true that during the first days of lactation both Holstein and Jersey x Holstein cows decreased their BCS due to in this time they mobilize body fat to cover the energy demand that the metabolism high produce during the production (Britt *et al*., 2003). However, the Jersey x Holstein have recovery during this critical time than Holstein cows. On the other hand, some authors have observed changes to increase the BCS even 3.5 the first 4 week of lactation in crossbred Karan Fries (Aggarwal *et al*., 2013). Therefore, it seems that the crossbred animals are more efficient in recovering their BCS. Transition cows with high BCS lose more body weight and body condition than thinner cows (Aggarwal *et al*., 2008). In other study, BCS before and after calving were different between Holstein and Norwegian x Holstein cows (Rinell and Heringstad, 2018). Finally, dairy cows under heat stress conditions, decrease appetite and nutrient availability, causing low weight, negative energy balance and reduction in BCS (Rhoads *et al.*, 2009, 2011). In fact, it has been observed that ewes with low condition, have more difficulty to eat than animals with high condition (Verbeek *et al.*, 2012).

YIELD IN CROSSBREDS

Usually, the responses between crossbreds and environments different on fat (%), protein (%), and milk yield are very variables such as it indicated Table VI. Like is known the milk yield in Holstein dairy cows is very greater than others crossbred or purebred cows (Touchberry, 1992; McAllister *et al.*, 1994). Heins *et al.* (2006) reported statistical differences between fat and protein yield when evaluating crossbreds different, where Holstein cows (Fat=346, Protein=305 kg) producing greater amount (P<0.05) of fat and protein than Normande x Holstein (Fat=319, Protein=277 kg), and Montbeliarde x Holstein (Fat=334, Protein=293 kg) cows. However, producing significantly the same amount (P>0.05) than Scandinavian Red x Holstein (Fat=340, Protein=297 kg) due to milk produced amount. Heins *et al.* (2008b) found significantly different (P<0.05), and reported 223 and 238 kg protein yield, respectively to Jersey x Holstein and Holstein. Studies have shown that Jersey x Holstein cows tended (P<0.10) to less milk yield than Holstein cows, but in the end both breed cows have the same (P>0.05) milk yield (Heins *et al.*, 2008a). The standpoint it is well, so at

Table V.- Sources of study.

Reference	Average THI, TZ and BGT	Location	Crossbred and percent
Heins *et al.* (2006)	Both	California, USA	Nomande (50) x Holstein (50) Montbeliarde (50) x Holstein (50) Scandinavian Red (50) x Holstein (50)
Heins *et al.* (2008a)	TZ	Minnesota, USA	Jersey (50) x Holstein (50)
Heins *et al.* (2008b)	TZ	Minnesota, USA	Jersey (50) x Holstein (50)
Khongdee *et al.* (2010)	THI= 80.13 ± 0.45	Sakol Nakhon, Thailand	Brahaman (12.5) x Holstein (87.5)
Khongdee *et al.* (2006)	THI=>72	Sakol Nakhon, Thailand	Thai (12.5) x Holstein (87.5)
Boonkum *et al.* (2011)	THI=73 all year THI=80 April to July	Pathumthani and other provinces, Thailand	Thai (6.4-12.5) x Holstein (87.5-93.6)
Auldist *et al.* (2007)	TZ	Gippsland, Australia	Jersey (25,50,75) x Holstein (25,50 y 75)
Dikmen *et al.* (2009)	THI=>72	Florida, USA	Jersey (50) x Holstein (50)
Chaiyabutr *et al.* (2008)	THI=81 ± 2.9	Thailand	Red Shindi (87.5) x Holstein (12.5)
Barbosa *et al.* (2008)	THI=>72	Pernambuco, Brazil	Gir x Holstein (25, 50, 62.5, 62.5-*inter se*)
Bun *et al.* (2018)	THI=>80	Phnom Penh, Cambodia	Cambodian native zebu (50) × Holstein-Friesian (50)
Kamila *et al.* (2018)	TZ	Worgule, Poland	Normande (50) x Holstein (50) Norwegian Red (50) x Holstein (50) Danish Red (50) x Holstein (50) Brown Swiss (50) x Holstein (50) Montbeliarde cattle (50) x Holstein (50) Simmental(50) x Holstein (50)
De Paula Xavier de Andrade *et al.* (2017)	THI=maximum 80	Pernambuco, Brazil	Zebu (25) x Holstein (75) Zebu (12.5) x Holstein (87.5)
El-Tarabany and El-Tarabany (2015)	THI=máximum 90	Cairo, Egypt	Brown Swiss (50) x Holstein (50)
Da Costa *et al.* (2015)	THI=>80	Ceará, Brazil	Gyr (75) x Holstein (25) Gyr (50) x Holstein (50)
Santos *et al.* (2017)	BGT=>80	Paraiba, Brazil	Gyr (12.5) x Holstein (87.5)

THI, temperature-humidity index; TZ, thermoneutral zone; BGT, black globe temperature.

Table VI.- Productive variables on crossbred dairy cattle differences.

Crossbred group	n	Milk lactation number and DIM	Milk yield (kg)	Fat (%)	Protein (%)	Reference
Nomande x H	245	1, 40	27.96 ± 1.66^{b}	3.74 ± 0.08	3.24 ± 0.05	Heins *et al.* (2006)
Montbeliarde x H	494		30.03 ± 1.66^{b}	3.64 ± 0.08	3.20 ± 0.05	
Scandinavian Red x H	328		30.42 ± 1.66^{b}	3.66 ± 0.08	3.20 ± 0.05	
Holstein	380		31.99 ± 1.66^{a}	3.55 ± 0.08	3.13 ± 0.05	
Jersey x Holstein	24	1, 4-150	29.25 ± 1.21*	3.83 ± 0.17	3.12 ± 0.09	Heins *et al.* (2008a)
Holstein	17		30.96 ± 1.21*	3.59 ± 0.17	3.08 ± 0.09	
Jersey x Holstein	76	1, 305	23.43 ± 1.29^{a}	2.74 ± 0.03	2.23 ± 0.03	Heins *et al.* (2008b)
Holstein	73		25.26 ± 1.29^{b}	2.77 ± 0.03	2.38 ± 0.03	
Jersey x Holstein (kg/d)	378	-	26.90 ± 2.46^{a}	4.04 ± 0.24^{a}	3.40 ± 0.10^{a}	Auldist *et al.* (2007)
Holstein (kg/d)		-	29.10 ± 2.46^{b}	3.70 ± 0.24^{b}	3.26 ± 0.10^{b}	
Jersey x Holstein (kg/d)	1200	1-2, 150	15.80 ± 1.2^{c}	-	-	Dikmen *et al.* (2009)
Jersey (kg/d)			16.30 ± 1.1^{b}	-	-	
Holstein (kg/d)			19.40 ± 1.0^{a}	-	-	
Brahman x Holstein (day^{-1})	8	2 and 3,60-70	8.38 ± 0.87	3.25 ± 0.41	3.10 ± 0.28	Khongdee *et al.* (2010)
Thai x Holstein (head^{-1} day^{-1})	7	2 and 3, 60-70	8.28 ± 0.12	-	-	Khongdee *et al.* (2006)
Thai x Holstein (test-day milk yield)	-	3, 64-230	13.8 ± 5.4	-	-	Boonkum *et al.* (2011)
Red Shindi x Holstein(early lactation)	18	1, 68 ± 5	12.6 ± 2.5	4.04 ± 2.08	3.32 ± 0.18	Chaiyabutr *et al.* (2008)
Red Shindi x Holstein (mid-lactation)		1, 125 ± 11	11.8 ± 3.2	3.38 ± 0.70	3.19 ± 0.24	
Red Shindi x Holstein (late lactation)		1, 210 ± 10	7.9 ± 3.1	4.00 ± 0.77	3.45 ± 0.19	
Gir x Holstein (25%)	1212	-	5.34 ± 0.46	4.08 ± 0.12	-	Barbosa *et al.* (2008)
Gir x Holstein (50%)		-	8.61 ± 1.16	4.45 ± 0.29	-	
Gir x Holstein (62.5%)		-	7.42 ± 0.39	3.87 ± 0.10	-	
Gir x *inter se* (62.5%)ǂ		-	5.76 ± 0.46	3.89 ± 0.12	-	
Normande x Holstein	10	2, 150 ± 21	18.93 ± 4.40*	3.59 ± 0.58*	4.77 ± 0.16*	Kamila *et al.* (2018)
Norwegian Red x Holstein	10		25.44 ± 7.71*	3.40 ± 0.15*	3.91 ± 0.63*	
Danish Red x Holstein	10		20.70 ± 6.51*	3.19 ± 0.28*	4.21 ± 0.80*	
Brown Swiss x Holstein	10		23.13 ± 5.00*	3.23 ± 0.27*	4.79 ± 0.68*	
Montbeliarde cattle x Holstein	10		28.00 ± 3.94*	3.02 ± 0.24*	3.61 ± 0.63*	
Simmental x Holstein	10		23.63 ± 4.51*	3.22 ± 0.32*	3.91 ± 1.55*	
Zebu x Holstein	8	-, 80	20	-	-	De Paula Xavier de Andrade *et al.* (2017)
Gyr (50) x Holstein (50)	60	1, 20-30	3937 ± 87^{a}&	-	-	Da Costa *et al.* (2015)
Gyr (75) x Holstein (25)	60		4262 ± 116^{b}&			

Means with different superscripts within a row are significantly different ($P < 0.05$). Means with same signal within a row have showed tend ($P < 0.10$). ǂ*inter se*, Holstein x Zebu; &, from September to November.

the end of the day Holstein cows produce greater fat and protein yield, due to produce greater milk yield. Auldist *et al.* (2007) found that Jersey x Holstein cows (26.90 kg) had significantly (P<0.05) less milk that Holstein (29.10 kg), but breed groups did not differ for fat or protein percent. It is very common not reported statistic differences in fat and protein percent (Heins *et al.*, 2006, 2008a, b) between crossbred and Holstein cows. In agree a study proves that Holsteins had on average 5% higher fat and protein yields in parities 1 to 3 but Norwegian Red x Holstein had higher fat and protein percentages (Ezra *et al.*, 2016). Also, other authors agree with these same results (Heins *et al.*, 2008b; Bryant *et al.*, 2007; Madgwick and Goddard, 1989; Lesmeister *et al.*, 2000). Higher concentrations of fat and protein in milk from Jersey x Holstein cows compared with Holstein cows resulted similar daily yields of fat and protein between breed groups. This is significant to Victorian herd owners, who are paid for milk based on the quantities of fat and protein supplied, with a penalty for milk volume. Dikmen *et al.* (2009) reported significantly differences (P<0.05) in milk yield, and not is amazing that Holstein (19.4 kg) cows produce more milk than Jersey x Holstein (15.8 kg), and Jersey (16.3 kg) cows. However, these authors explain that differences in milk yield between genotypes were small, probably because the level of nutrition did not allow Holsteins to realize their genetic potential for milk yield. Perhaps genotype differences in thermoregulatory ability would be greater than seen here if there were greater differences in milk yield between genotypes. Heterosis has been demonstrated for several traits in dairy cattle including milk yield, fat and protein percentage of the milk, incidence of diseases and reproductive traits (Sørensen *et al*., 2008). Several studies used crossbred dairy milk cows under heat stress and have shown less milk yield that not reach an average of 14 kg, but fat and protein percent high produce (Khongdee *et al*., 2010, 2006; Boonkum *et al*., 2011; Chaiyabutr *et al*., 2008; Barbosa *et al*., 2008). Many studies agree, also reported low milk yield in dairy milk cows under heat stress (Table II). This suggests that heat stress impact on milk yield is accumulative regarding at time (De Boer *et al*., 1989; Barash *et al*., 2001). The declining of milk yield on crossbreds cows was found at a THI of 80 (Boonkum *et al*., 2011). The THI threshold of 80 is higher than the thresholds of 72 to 76 reported for US Holsteins (Ravagnolo *et al*., 2000; Freitas *et al*., 2006a, b; Aguilar *et al*., 2009). High environment temperature cause low efficiency of energy for milk produces (Wayman *et al*., 1962; Habeeb *et al*., 2018). Suggesting, animals under heat stress the energy costs are used mostly for heat dissipation mechanism (*e.g.* sweating rate), and not are used for milk produce (Chaiyabutr *et al*., 2008). Then, if consume rate energy decrease within mammary could be affecting the activities of epithelial cells within mammary gland. In context, the transport of glucose for utilization in the mammary gland has been noted to depend on the specific glucose transporter at the mammary cell membrane (Prosser, 1988; Madon *et al*., 1990; Avendaño *et al*., 2012), and the rate-limiting step for glucose transport at the mammary cell (Chaiyabutr *et al*., 2007). Barbosa *et al.* (2008) not reported significantly different (P>0.05) milk yield and fat percent on Gir x Holstein with 25 (5.34 kg and 4.08%), 50 (8.61kg and 4.45%), 62.5 (7.42 kg and 3.87%) Holstein blood cows, and 62.5 *inter se* (5.76 kg and 3.89 %) Holstein and Zebu blood cows. Genetic group with 50% Holstein had shown numerically difference greater amount of milk and fat percent as expected, the maximum heterosis occurred in this genetic group and was probably determined by non-additive genetic effects. This was true even for fat percent, which normally presents high estimates of heritability (Barbosa *et al*., 2008). Think suggested that in hot climates the first crossbred generation, under optimum management and feeding conditions, can be used for dairy purposes (McDowell *et al*., 1996). Lobo *et al*. (1984), working in Brazil with five generations of Pitangueira breed cows reported a significant advantage in milk yield of the F_1 generation regarding milk yield of other generations, although there were no important differences between the remaining generations. Animals having on average 75% Zebu, the crossbred cows are generally less productive. Syrstad (1989) concluded that there was a reduction of approximately 24% in milk yield in *inter se* crossbred cows, probably as a consequence of a reduction in heterozygosity from the F_1 to F_2 generations due to discontinuity in the combinations of the epistatic genetic effects (Syrstad, 1989). In other words, although the crossbreds usually produces less milk than Holsteins, crossbreeding improves health and fertility (Rinell and Heringstad, 2018).

CONCLUSIONS

The crossbred dairy cows improve considerably body condition score, respiration rate, rectal temperature, and they own higher tolerance at heat than purebred cows. Milk yield not improves regarding Holstein cows, but fat and protein percent it is greater than Holstein cows. Apparently the crossbred in dairy cattle is the answer to improve productive and physiological responses dependent upon environment, however, does not exist crossbred in dairy cattle perfect. Crossbreeding of dairy cattle is being explored mostly for its potential to improve the fertility, health, and survival of cows, and advantages for these traits might compensate for loss in production of crossbreds compared to pure Holsteins. There have been many crossbreeding programs in dairy cattle, but when the producer choose a system crossbreeding in dairy cows always mostly contemplate only body weight, body condition score, dry matter intake, and feed efficiency. Is necessary, contemplate other traits like genetic potential, lactation (305 d), lactation number, fertility rate, and economic impact to observe clarity the potential of each crossbred in dairy cattle in the future.

According to the concepts discussed in this review, we sustain that crossbreeding in dairy cattle improves certain productive and physiological responses diminishing the effect of environmental heat stress.

Statement of conflict of interest

Authors have declared no conflict of interest.

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