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Assessing climate vulnerabilities and adaptive strategies for resilient beef and dairy operations in the tropics

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Abstract Cattle ranchers and dairy farmers operating throughout many tropical regions are experiencing major challenges associated with climate change such as higher incidence of heat stress and drought. These effects can result in reduced productivity of rangeland, shortage of nutritional feed, increased heat stress on animals, and high energy costs for cooling. High temperatures and resultant heat stress reduce animal productivity and increase the proliferation and survival of parasites and disease pathogens. Warming reduces the ability of dairy cattle to produce milk and gain weight and can also lower conception rates. This paper reviews research from the Caribbean on heat tolerant traits in bovine and presents evidence that introducing a "slick hair" gene into Holstein cows by crossbreeding with Senepols may increase thermotolerance and productivity. As in other parts of the tropics, principal cattle breeds in Puerto Rico and the US Virgin Islands have been largely introduced from temperate regions. Research indicates these animals may be poorly adapted to rising temperatures, leaving them increasingly vulnerable to chronic heat stress and reduced productivity. Adaptive practices have been developed in breeding and pasture management programs including selection for more heat-resistant genotypes, silvopasturing and crop diversification in forage production, and optimizing facilities and practices to reduce heat stress. Given the nature of climate vulnerability, an integrated approach to adaptation will likely have the greatest success in reducing future risk for producers.

Keywords Climate change · Holstein · Senepol · Adaptation · Agriculture · Cattle

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1 Introduction

This paper briefly summarizes climate projections for the Latin American Caribbean (LAC) and the US Caribbean (Puerto Rico and the US Virgin Islands), discusses how shifts in climate may interface with vulnerabilities in the beef and dairy sector, and presents resent findings on heat tolerant genotypes in Puerto Rican cattle that could prove relevant to adaptation efforts throughout the tropics.

The earth's surface and ocean temperatures will increase over the twenty-first century under all assessed emission scenarios (Allen et al. 2014). The Intergovernmental Panel on Climate Change (IPCC) predicts that global average temperatures could rise by 0.3 to 4.8 °C (0.5–8.6 °F) by 2100 (Allen et al. 2014). The range of increase projected varies according to the emission scenario and climate model. Karmalkar et al. (2013) projected a 2–5 °C (3.6–9 °F) increase for the LAC by 2080–2089 as compared to 1970–1989 based on the SRES A2 emission scenario. Interpolation of downscaled climate data for Puerto Rico has resulted in higher projections for the period 2071–2099 (7.5 to 9 °C or 13.5 to 16.2 °F) (Henareh Khalyani et al. 2016). If global efforts to limit average global warming to 1.5 °C recently ratified at the Paris UNFCC COP are successful, downscaled models indicate Puerto Rico may still experience a dramatic increase in total dry days and days that exceed historical temperature maximums (particularly in the wet season) (Hayhoe 2013). Prolonged dry periods are expected to become more frequent throughout much of the Caribbean with even 1 °C of average global warming (Hayhoe 2013). Modeling indicates much of the mean temperature increase in the LAC is due to increases in mean minimum temperatures indicating a narrower range of temperature variation (both annual and diurnal) and sustained higher temperatures (Hayhoe 2013, Karmalkar et al. 2013).

In recent years, drought and intense heat have negatively affected beef and dairy producers in the US Caribbean. Dairy is an important farming sector in Puerto Rico and throughout the Caribbean, involving more than 50,000 acres and generating over 25,000 jobs in Puerto Rico alone (Ortiz-Colón 2011). In 2014, the dry season in the US Virgin Islands was extreme, sparking wildfires that affected livestock and ranchers. Intense heat and lack of rain withered grasses in the summer of 2015, forcing producers to take drastic measures including collecting palm fronds and tree branches for fodder, relying on imported feed, and culling herds. In Puerto Rico, the same drought forced ranchers to more heavily on costly imported feed. Many also saw milk production goes down as heat stress and lack of nutrients took their toll on local herds. Regional climate models are predicting more frequent occasions in which prolonged periods of drought are punctuated by intense storm and rainfall events (Hayhoe 2013, Karmalkar et al. 2013).

1.1 Beef and dairy industry in Puerto Rico and the US Virgin Islands

The dairy industry is the leading agricultural enterprise in Puerto Rico and has been for the past four decades (National Agricultural Statistics Service 2014). From 1996 to 1997, the dairy industry in Puerto Rico boasted 425 dairy farms, three processing plants, and 90,000 dairy cows that together generated over 28% ($194 million) of the agricultural revenues (Ramírez 1998). In 2014, there were 320 dairy farms on the island that contributed $212.7 million to the economy, representing 22.9% of the gross farm income for that year (RODI 2014). The dairy industry generates around 25,000 direct and indirect jobs, but faces enormous challenges associated with high production costs, inefficient herd management, poor nutritional programs, and low forage production (Ortiz-Colón 2011). Overgrazing and poor quality forage have forced farmers to rely on costly imported concentrated feed to maintain productivity. While the amount of milk produced per cow has tripled in the continental USA from 2683 kg/lactation to more than 8942 kg/lactation, milk production in Puerto Rico has increased only 1341 kg per lactation during the last five decades (Ortiz-Colón 2011).

The beef industry confronts serious challenges as well and has severely declined over the last decades. In 1950, Puerto Rico produced 10.54 million kg of beef, which represented 74.4% of total local consumption (Centro de Recursos Informativos Agrícolas de Puerto Rico 2018), and the average per capita consumption was 6.36 kg per person (NASS 2014). Beef imports began to increase dramatically in the 1960s; however, local production did not begin to decline until 1990 (Casas-Guerníca 2010). During the 1990s, Puerto Rico surpassed the US mainland in terms of imported more beef relative to local production and population. (Duewer et al. 1989). After the establishment of the farm-to-school program in 2000, there was a small increase in production that supplied local beef to schools. Since that time, local production has stabilized, but not increased. In 2010, total beef consumption reached 71.27 million kg, with only 7.82 million kg (10.9%) being produced locally (Centro de Recursos Informativos Agrícolas de Puerto Rico 2018). Since the 1970s, the per capita consumption of beef has remained stable at an average of 42.1 lb per year (Centro de Recursos Informativos Agrícolas de Puerto Rico 2018). In 2011, the beef industry included 500 ranching families and employed about 4000 people (Araújo 2011). By 2014, there were 800 beef cattle ranchers in Puerto Rico producing 7.7 million kg annually, encompassing 9% of the total local consumption. Meat and related products comprise 27% of local food consumption and represent the largest portion of food-related expenditures compared to 24.7% spent on fruits and vegetables and 11% on dairy and related products (Monclova 2014).

The US Virgin Islands are known worldwide for developing the heat-tolerant Senepol cattle breed with traits suitable for tropical climates, including heat tolerance, insect and disease resistance, and its ability to thrive on poor quality forage. However, the beef and dairy industry of the US Virgin Islands has been declining in recent decades, particularly in St. Croix where the dairy cooperative that supplied much of the Islands closed at the end of 2011 (Blackburn 2011).

2 Vulnerabilities in the beef and dairy sector of the US Caribbean

One of the greatest challenges to beef and dairy production in the Caribbean is heat stress (Ortiz-Colón 2011). High temperatures and heat stress reduce the animal's productivity and increase the proliferation and survival of parasites and disease pathogens. Warming reduces the ability of dairy cattle to produce milk and gain weight and also lowers conception rates. The principal bovine breeds in Puerto Rico and the US Virgin Islands have been imported from temperate regions, increasing their vulnerability to chronic heat stress and reduced dairy productivity in the face of climate change (Ortiz-Colón 2011).

For European cattle breeds localized in the tropics, heat stress is chronic and usually, there is only small heat relief at night, if any (Berman 2011). Intense radiant energy year round significantly adds heat loads to animals. The tropics are particularly harsh for European dairy cows that generate a large amount of metabolic heat when lactating (Wheelock et al. 2010). High environmental temperatures associated with the tropics, coupled with metabolic heat production and diminished cooling capability due to high humidity, result in higher body temperatures, depressed dry matter intake, and low milk production (West 2003). As climate change threatens extended periods of aggravated environmental stress across the world, negative effects on the productivity, reproduction, and welfare of beef and dairy cattle would be a significant consequence worldwide (Berman 2011).

3 Adaptive strategies

To minimize the effects of heat stress, three general management strategies have been identified: (1) physical modification of the environment, (2) improved nutritional management practices, and (3) genetic development of heat-tolerant breeds (Beede and Collier 1986). Here we focus on recent findings related to the third strategy. Unfortunately, heat tolerance is negatively correlated with production (−0.3, Ravagnolo and Misztal 2000). Therefore, if selection for higher milk production continues while ignoring heat tolerance, the result would be a progressive decrease in heat tolerance in dairy breeds (West 2003). However, because the negative correlation between milk production and heat tolerance is small, a combined selection for milk production and heat tolerance is possible (West 2003). Due to the uncertain effects climate change may have on dairy cattle productivity, research of intrinsic differences exhibited by heat tolerant breeds would be invaluable in the quest to genetically select for thermal tolerance. The ultimate goal is to maintain high milk production efficiency in warmer climates.

3.1 Heat tolerant bovines

European cattle arrived on the island of Puerto Rico with the Spanish conquest in 1511 (Molina-Fernández 2001). For more than 500 years, farmers in Puerto Rico selected for tolerance to the hot and humid environment of the island (Molina-Fernández 2001). In the 1950s, there was a large influx of European dairy breeds, primarily Holsteins, which farmers began crossing with the more traditional verities of cattle in the islands (Molina-Fernández 2001). Sixty-five years later, we find registered Holsteins with higher milk production (Fig. 1) and shorter calving interval (Fig. 2) than their wild-type contemporaries (Pantoja et al. 2005).

Dairy farmers in Puerto Rico used to call these Holsteins "rabifinas" which literally translates to "slick tails", describing their very fine tails that are almost devoid of hair (Fig. 3). These "rabifinas" also exhibit a very short, sleek, and mostly glossy coat very similar to the phenotype described by Olson et al. (2003) after introducing the Slick gene from Senepols into Holsteins. However, in Puerto Rico, farmers selected for "rabifinas" decades before Senepol cattle were introduced into Puerto Rico in 1983. Moreover, the use of Senepol cattle as a commercial beef breed was extremely limited until the late 1990s. According to testimony from dairy farmers with "rabifinas," Senepol bulls have never been used in their dairy herds (López-López 2015; Borges 2015). This presents the possibility that the mutation that causes the Slick phenotype of the rabifinas might be different than the gene responsible for this phenotype in Senepol cattle (Olson et al. 2003).

Although Senepol cattle were traditionally thought to be descendants of Red Poll × N'Dama cattle, recent evidence indicates that Senepol is 89% European, 10.4% Zebu, and only 0.6% of African ancestries (Flori et al. 2012). Indeed, de Alba (1987) questioned the N'Dama contribution into the Senepol breed and suggested that Criollo cattle (presumably mostly of European descent) imported into St. Croix from Puerto Rico (Vieques Island) could have been major contributors to the Senepol breed along with the Red Poll and some Zebu

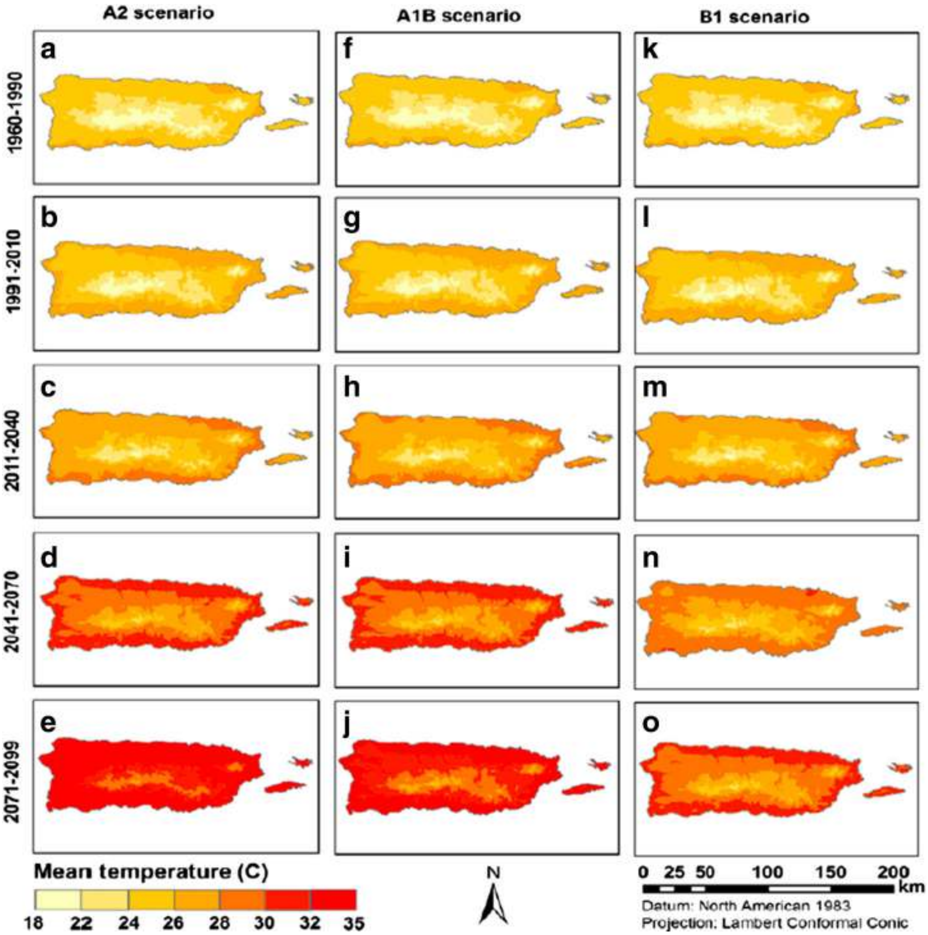

Fig. 1 Projected mean annual temperature increase for Puerto Rico. Source: Henareh Khalyani et al. 2016

blood. Therefore, it could be possible that Senepols and Holsteins "rabifinas" could share a common ancestor that imparted the slick gene to both. In the quest to better understand genetic adaptations to heat stress, it would be important to characterize intrinsic differences between different cattle populations that exhibit the Slick phenotype and their non-slick breed members.

3.2 Slick genotype

A valuable strategy to decrease the severity of heat stress impact on dairy cattle is the selection of animals with improved thermo-tolerance. Indeed, specific single nucleotide polymorphisms (SNP) have been associated with thermo-tolerance in Holsteins (Hayes et al. 2009; Dikmen et al. 2012; Dikmen et al. 2014). However, only a few specific genes have been associated with heat tolerance (Ravagnolo and Misztal 2000). One such gene is the slick-hair gene (slick). The Slick phenotype was originally described by Tim Olson and collaborators in Senepol cattle that inherited a single dominant gene (Olson et al. 2003). The Slick haplotype provides cattle

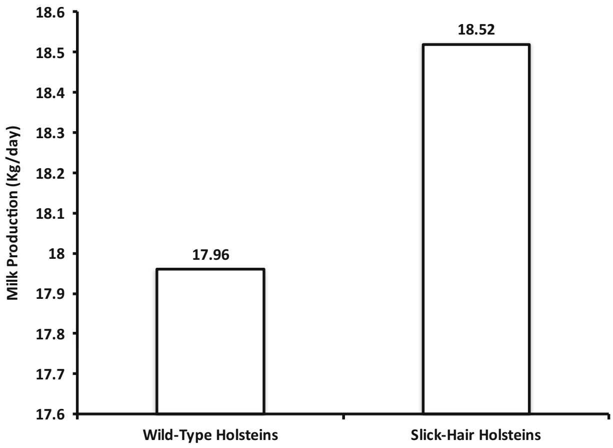

Fig. 2 Comparison of milk production between wild-type Holsteins and Slick-hair Holsteins in Puerto Rico. DHI records were used to compare the production of 54 slick-hair Holstein cows against their contemporaries across Puerto Rico. Wild-type and slick-hair dairy cows were distributed across 12 dairy farms across the island. (Adapted from Pantoja et al. 2005)

animals with "short and sleek hair" and sometimes a "glossy coat" (Olson et al. 2003). Since then, the Slick locus has been mapped in bovine chromosome (Chr) 20 (Mariasegaram et al. 2007; Flori et al. 2012).

By 2003, Olson et al. had successfully introduced the slick-gene into Holsteins by crossbreeding Senepol with Holstein cows. The resulting offspring (slick-haired Holstein) have been shown to have lower vaginal temperatures and lower respiration rate than wild-type Holstein cows (Dikmen et al. 2008). In this experiment, however, although slick-haired Holsteins showed greater sweating rates in unclipped areas of skin, clipping the hair at the site of sweating measurement eliminated the difference between slick-haired and wild-type cows (Dikmen et al. 2008). This result presents the possibility that the main impact of the slick

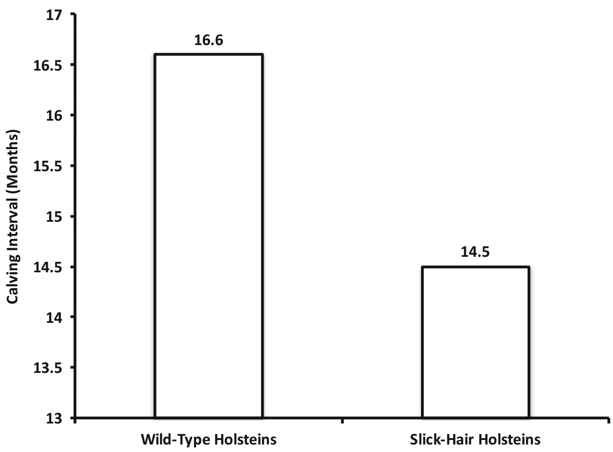

Fig. 3 Calving interval comparison between wild-type and slick-hair Holsteins in Puerto Rico. DHI records were used to compare the production of 54 slick-hair cows against their contemporaries across Puerto Rico . Wild-type and slick-hair dairy cows were distributed across 12 dairy farms across the island. (Adapted from Pantoja et al. 2005)

gene on thermo-tolerance could be primarily associated with an improvement in the ability to dissipate heat through sweating. Indeed, in a later study with the objective of evaluating whether the lactation performance of slick-hair cows could be simulated through hair clipping found that milk yield was higher (13.4 vs. 10.8 ± 0.26 kg/d, $p = 0.003$) among clipped cows (Mejía et al. 2010). The fact that clipped hair cows showed a decrease in rectal temperature and an increase in milk production further suggests that the main effect of slick-haired genotype is reduced hair length. The short hair length caused either by the Slick haplotype or by hair clipping could result in reduced insulation to conductive and convective heat loss in the hair coat, resulting in an improved thermo-tolerance (Berman 2011).

A more recent study compared the thermo-regulation capacity of lactating Holsteins with the slick-hair phenotype with relatives not inheriting the Slick haplotype or with wild-type Holstein cows (Dikmen et al. 2014). Lower vaginal or rectal temperatures were found in slick-haired cows than in relatives and wild-type cows. Moreover, the increase in respiration rate caused by heat stress during the day was lower for slick-haired cows than for relatives or wild-type cows. Furthermore, sweating rate was higher for slick-haired cows than for cows of the other two types. The superior thermoregulatory ability of Holsteins with slick hair compared with non-slick animals also resulted in a less drastic depression in milk yield during the summer (Dikmen et al. 2014). Importantly, in this experiment, cows that were relatives of slick cows but that did not inherit the Slick phenotype still exhibited enhanced thermoregulation when compared with wild-type Holsteins. This evidence strongly suggests the Slick haplotype

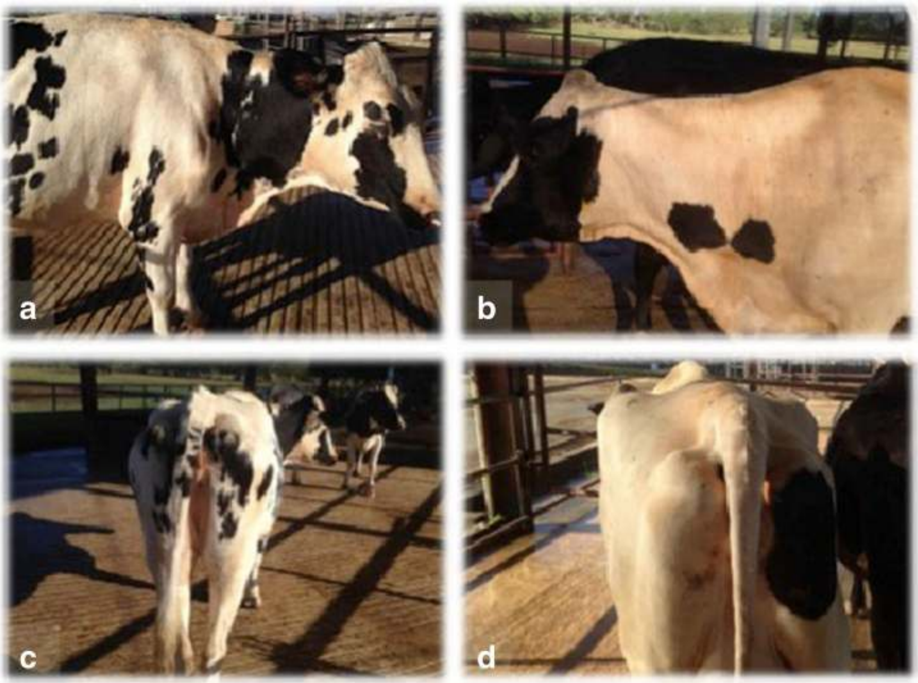

Fig. 4 Comparison of hair phenotype between wild-type Holsteins and Slick-hair Holsteins at the Puerto Rico Experimental Dairy Farm. **b**, **d** show an example of the "slick" appearance of the Holsteins adapted to the tropical conditions of Puerto Rico, **a**, **c** show an example of a wild-type Holstein. (Curbelo-Rodríguez, unpublished)

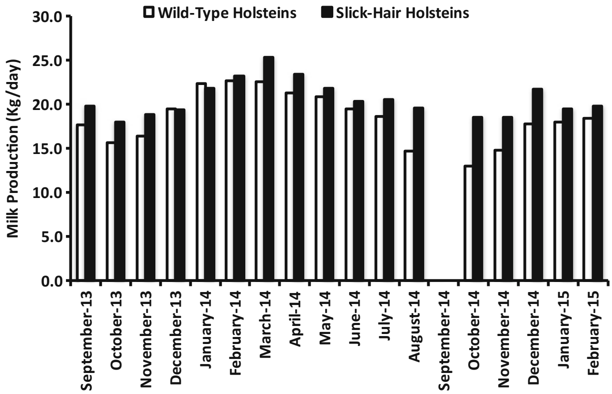

Fig. 5 Comparison of milk production between wild-type Holsteins and Slick-hair Holsteins in one dairy farm of Puerto Rico. DHI records (DHI 202) were used to compare the production of 19 to 26 slick-hair cows against their 61 to 96 wild-type contemporaries (animal numbers varied depending on the test date)

is not the only gene conferring thermo-tolerance (Dikmen et al. 2014) and that unknown intrinsic differences that offer thermos-tolerance through more complex mechanisms than just hair length might exist between Slick and wild animals. Indeed, in this same experiment, seasonal alterations in percentage of fat, protein, and lactose in addition to somatic cell counts were intensified in slick-haired cows (Dikmen et al. 2014). These results strongly indicate that the Slick haplotype is associated with the regulation of milk synthesis and the immune response. Undoubtedly more research is necessary to explore possible intrinsic differences that might exist between slick and non-slick Holstein cows.

3.3 Preliminary data

Since September 2013, we have been observing the behavior of registered Slick Holstein cows in a commercial dairy farm in Puerto Rico. Since that time, we have been able to document through Dairy Herd Improvement (DHI) daily test records, generally higher milk production in slick-haired cows compared to their non-slick contemporaries (Fig. 4).

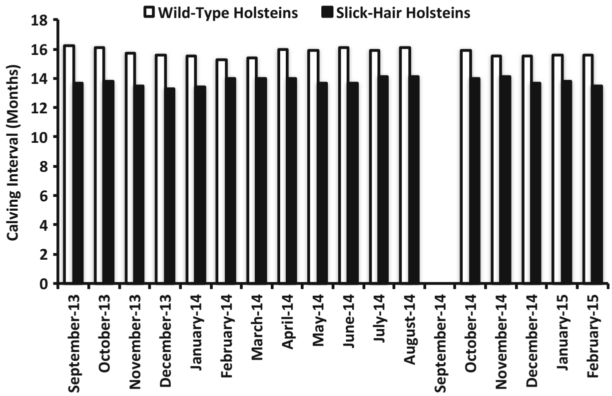

Fig. 6 Comparison of calving interval between wild-type Holsteins and Slick-hair Holsteins in one dairy farm of Puerto Rico. DHI records (DHI 202) were used to compare the production of 19–26 slick-hair cows against their 61–96 wild-type contemporaries (animal numbers varied depending on the test date)

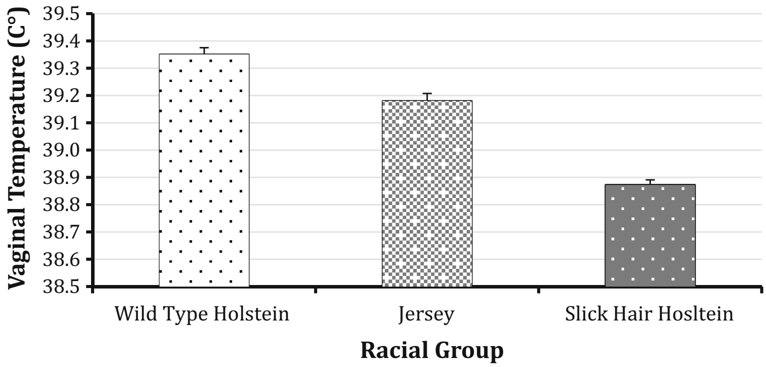

Fig. 7 Average vaginal temperature of three bovine racial groups over a 5-day period managed under tropical dairy system. Means with different superscripts differ ($p < 0.05$). Adapted from Curbelo-Rodríguez et al. 2016

Additionally, on average, registered Slick Holsteins have a shorter calving interval by 1.97 months. While non-slick present a calving interval of 15.76 months on average, slick-haired cows have a calving interval of 13.79 months (Fig. 5).

Preliminary data generated in another commercial dairy herd in Puerto Rico using three commonly employed dairy breeds ($n = 4$ per breed) demonstrated that slick-haired Holsteins have lower ($p = 0.0055$) vaginal temperature relative to Jersey and wild-type Holsteins over a 5-day period (Fig. 6) and under different environmental scenarios ($p < 0.05$, Fig. 7) (Curbelo-Rodríguez et al. 2016). Furthermore, we have documented differences in genotypic between Slick and non-Slick Holsteins. For example, genotypic frequencies at position A-278G from the promoter region of the FSH receptor are different between Slick and Non-Slick dairy cows (Figs. 8 and 9) (Patiño-Chaparro et al. 2014).

4 Discussion

Our research indicates dairy cattle better adapted to heat stress could have more efficient lactation under heat stress and likely would have better feed efficiencies

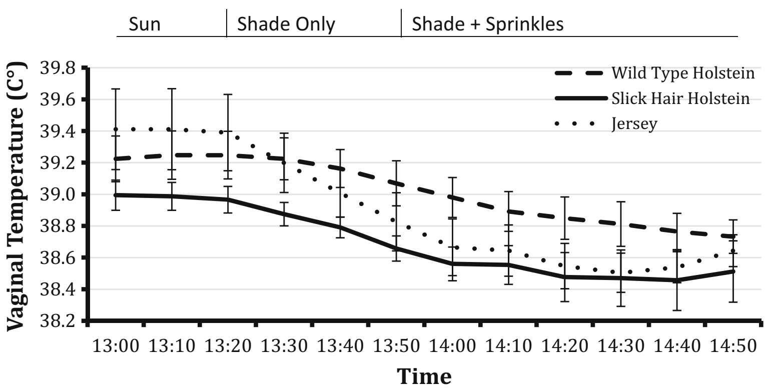

Fig. 8 Vaginal temperatures among dairy breeds under exposed to different environmental scenarios (sun, shade only, and shade plus sprinkles) in a dairy herd in Puerto Rico. Adapted from Curbelo-Rodríguez et al. 2016

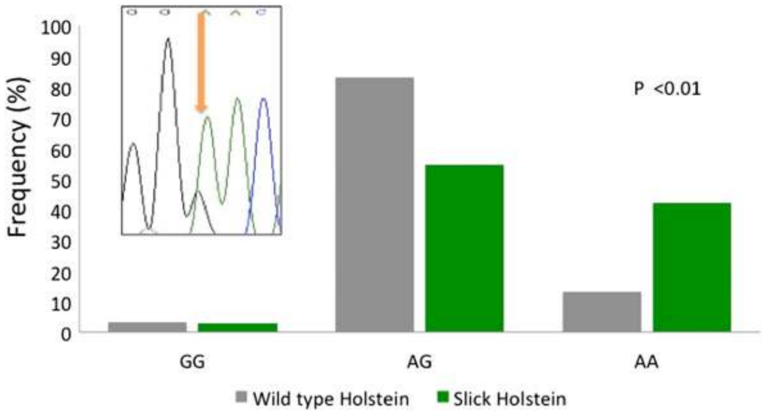

Fig. 9 Genotypic frequencies at position A-278G from the promoter region of the FSH receptor in Slick and Non-Slick (Wild-type Hostein cows). (Adapted from Patiño-Chaparro et al. 2014)

than non-adapted animals. Furthermore, thermos-tolerant dairy cattle could be less susceptible to metabolic disorder (i.e., ketosis) as feed intake would be less affected under heat stress conditions. With fewer, but more efficient heat tolerant dairy animals to produce a given amount of milk, the environmental impact of dairy production could be significantly mitigated. Heat-tolerant dairy cattle could also reduce production costs by reducing the need for heat abatement technology and the use of fossil fuels.

Given the uncertain effects climate change may impose on beef and dairy production, understanding the intrinsic differences and physiological mechanisms that provide animals with thermo-tolerance will be essential to promote an efficient, environmentally sustainable, and profitable industry, allowing it to continue contributing to the food security of the US Caribbean and broader tropics. Meaningful production differences of Slick bovines under heat stress suggest that the Slick phenotype could be an important adaptation for improved milk production in hot environments. Global climate projections indicate the need for more heat-tolerant cattle will become more urgent and widespread in the coming years.

5 Conclusion

Beef and dairy production is important to the food security and economy of the US Caribbean and the tropics at large. Regional climate projections indicate producers may find it increasingly necessary to adapt management practices in order to maintain productivity in a warmer world. If temperatures continue to rise as projected, the use of heat-resistant breeds like slick-haired Holsteins and Senepol may need to be coupled with other adaptive practices such as integrating shade and crop trees in grazing lands (silvopasture) or around facilities to lower ambient temperatures (Gould et al. 2015), modifying facilities to reduce heat stress on animals, and utilizing water and soil moisture conservation measures to minimize impacts of seasonal water shortages. Examples of successful adaptation within the US Caribbean, such as those offered in this paper, could provide useful prototypes for producers throughout the tropics facing similar climatic challenges.

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