# Breeding Focus 2018 - Reducing Heat Stress

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# Preface

“Breeding Focus 2018 – Reducing Heat Stress” is the third workshop in the series. The Breeding Focus series was developed to provide an opportunity for exchange between industry and research across a number of agricultural industry sectors. With this goal in mind, workshops have included presentations across the livestock and aquaculture industries to take participants outside their area of expertise and encouraged them to think outside the box. This year we increased the scope even further by also inviting presentations from the cropping and horticulture industries. Since the topic of heat stress has recently gained increased attention, we will discuss a wide range of aspects associated with heat stress, such as the physiology of heat stress and phenotypic indicators, genetic approaches and industry impacts.

Heat stress in animals describes a situation where an animal is exposed to high temperatures and unable to dissipate body heat, which causes an increase in body temperature. In the short term, an animal will react to heat stress with behavioural strategies (e.g. seeking shade, panting) to reduce the heat load. With prolonged excessive heat load, feed intake is reduced and production losses occur. Under extreme circumstances, excessive heat load can lead to death. In plants, heat stress can be defined as irreversible damage to plant function and development as a consequence of hot temperatures. Environmental causes of heat stress in plants and animals include high temperatures and high humidity over a long period of time, which is exacerbated by low cloud cover and high solar radiation.

With raising average temperatures, agricultural industries are faced with the challenge to manage potential impacts of heat stress on their crops, their pasture base and welfare and production of their livestock or aquaculture species. Management strategies such as shade and irrigation are effective but costly and, depending on the severity of climatic conditions, may have limited success. Susceptibility of organisms to heat stress can vary due to factors such as age and general health, but also genetic factors, such as breed or variety. Further, as we will hear during the workshop, genetic variation exists within breeds that enables genetic approaches to address heat stress in plants and animals. Selective breeding provides a long term approach that facilitates improvement of the physiology of plants and animals to cope with excessive heat load. The challenge here is to obtain cost-effective phenotypes to describe heat stress.

The chapters of this book discuss where the current climate is trending, and outlines opportunities for the crop, orchard, livestock and aquaculture industries to describe and measure heat stress, all with the focus on genetic improvement.

We would like to thank everyone who has contributed to this event for their time and effort: the authors for their contributions to the book and presentations, the reviewers who all readily agreed to critique the manuscripts. We would like to express a special thanks to Kathy Dobos for her contributions into the organisation of this workshop and the publication. Thank you!

Susanne Hermesch and Sonja Dominik
Armidale, September 2018

# A tool to breed for heat tolerant dairy cattle

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## Abstract

This paper describes the development, validation and implementation of a genomic breeding value for heat tolerance (HT GEBV) in Australian dairy cattle, which can be used as a tool to select animals with improved heat tolerance.

To develop a HT GEBV, we merged temperature and humidity weather data with milk production records that were collected between 2003 and 2016. The rate of decline of milk, fat and protein yield (namely cow slope) for 424,540 Holstein and 84,702 Jersey cows was calculated when temperature and humidity exceeded a defined comfort level. Slope of a sire represents the average cow slope for his daughters. A reference population consisting of 11,853 cows and 2,236 sires for Holsteins and 4,268 cows and 506 sires for Jerseys (both having estimated slope and high density genotypes), were used to derive a genomic prediction equation. This HT GEBV can then be used to estimate heat tolerance in other animals with genotypes.

To validate the HT GEBV, we predicted HT GEBVs for 390 Holstein heifers, then selected 24 extreme heifers predicted to be heat tolerant or heat susceptible and exposed these heifers to a 4-day heat challenge in controlled climate chambers. The predicted heat tolerant group showed significantly less decline in milk production and lower rectal and intra-vaginal temperatures compared to heifers in heat susceptible group. This suggested that the HT GEBV will enable selection for cattle with better tolerance to heat stress.

We expressed HT GEBV by applying economic weightings for decline in milk, fat and protein, as used by industry. Within each breed, the HT GEBV was then standardized to have a mean of 100 and standard deviation (SD) of 5. The mean reliabilities of HT GEBV among validation sires were 38% in both breeds. HT GEBV was found to be unfavourably correlated to production and favourably correlated to fertility. The HT GEBV was released by DataGene in Dec 2017.

## Introduction

Heat stress has become a challenge for many primary production sectors worldwide, including the dairy industry. Under high temperature and/or humidity conditions, animals experience heat stress. Heat stressed animals often reduce their feed intake, and as a consequence, reducing their milk yield and economic returns (Kadzere *et al.*, 2002, St-Pierre *et al.*, 2003). Heat stress is also known to reduce conception rates (Monty and Wolf, 1974, Folman *et al.*, 1983, Hansen and Aréchiga, 1999), and increase incidence of health problems and mortality in dairy cows (Kadzere *et al.*, 2002, Dikmen and Hansen, 2009).

Heat stress can be managed in several ways. Provision of cooling devices such as shades, fans and sprinklers, or managing milking time on hot days are strategies to alleviate the impacts of heat stress. In this context, the Cool Cows initiative of Dairy Australia has been developed to assist farmers. The Cool Cows website (http://www.coolcows.com.au/) provides forecast of heat events and suggests management options, including infrastructure improvements and allows producers to conduct cost-benefit analyses related to heat stress management. In addition, delaying milking time to after 5 pm could also reduce heat stress for cows during hot days (Cool Cows, http://www.coolcows.com.au/hot-season-strategies/milking-times.htm). Management of diets such as provision of slowly fermentable grains such as corn is also known to improve thermo-tolerance of dairy cows (Gonzalez-Rivas *et al.*, 2018).

Previous research on heat tolerance found that there is genetic variation in performance of dairy cattle under heat stress conditions (Hayes *et al.*, 2003, Bohmanova *et al.*, 2008). As such, identification and selection for heat tolerant animals is possible, and can offer a promising and long-term solution to address issues relating to heat stress and climate change. Compared to traditional breeding, genomic selection is better suited to select for heat tolerance as it enables faster genetic gain. The costs involved in genomic selection will also be minimal as the genotypes of thousands of cows and bulls are already available in Australia.

This paper aims to describe the development, validation and implementation of a genomic breeding value for heat tolerance (HT GEBV) in Australian dairy cattle. This new breeding value provides a new tool that enables farmers to select for improved heat tolerance in dairy cattle which was released nationally in Australia (by DataGene) in December 2017.

## Defining heat tolerance

Environmental heat load can be influenced by many factors such as temperature, humidity, wind speed and solar radiation. Thermoregulation in cattle is affected largely by air temperature and relative humidity. The temperature-humidity index (THI) combines temperature and humidity into a single value, and is the most commonly used index of environmental heat load.

Heat tolerance can be defined as the rate of decline in milk, fat and protein yields per unit increase of THI. Production in heat tolerant cows declines more slowly in response to increasing heat stress when compared to cows that are more susceptible to heat stress. Figure 1 provides an example of how cows can perform differently under heat stress conditions. Under the thermoneutral condition, that is within the comfortable zone, both cow A and cow B produce a similar amount of milk. However, when THI increases beyond the thermoneutral zone (the upper critical zone), representing heat stress conditions, cow B produces less milk than cow A. This indicates that cow A is more tolerant to heat stress compared to cow B.

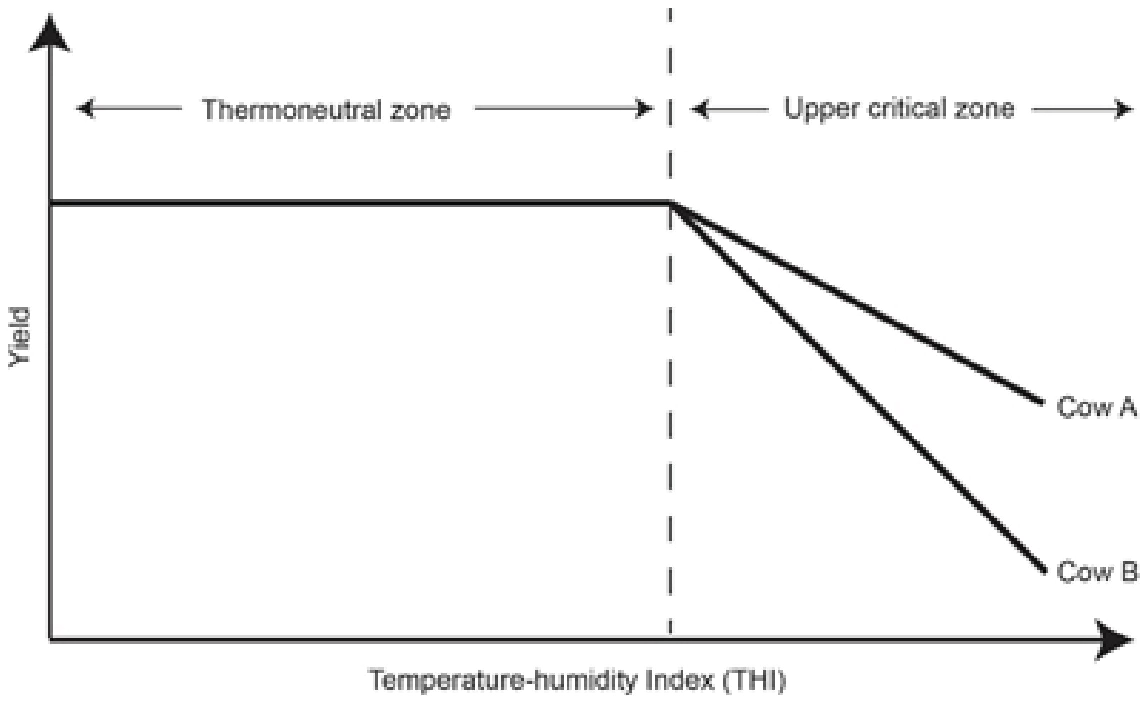


*Figure 1. An illustration of how cows can perform differently under heat stress conditions (adapted from Bloemhof et al. (2008).*

## Development of heat tolerance breeding value

Nguyen *et al.* (2017a) developed a HT GEBV using herd test records from 1,927 Holstein and 554 Jersey dairy herds, using the methods described in Nguyen *et al.* (2016). Briefly, herd test records from 424,540 Holsteins and 84,702 Jersey cows were combined with daily temperature and humidity measurements from weather stations closest to the tested herds, for test days between 2003 and 2016. The distance between a herd and a weather station was measured using the geographic positioning system (GPS) coordinates of the herd and that of the weather station, where possible. If GPS coordinates of a herd were unavailable, we used the GPS of the postcode centroid instead. Daily mean values of THI averaged for the day of test and the four previous days (THI) were used as the measure of heat stress.

Tolerance to heat stress was estimated for each cow using a reaction norm model (Nguyen *et al.*, 2016). The slope solutions for cows from this model were used to define the phenotypes of tolerance to heat stress of 2,236 Holstein and 506 Jersey sires, which were genotyped for 46,726 SNP. These sires, together with 11,853 Holstein and 4,268 Jersey cows which have genotypes, form a reference population which is a group of animals used for genomic prediction for Holsteins and Jerseys, respectively.

Genomic best linear unbiased prediction (GBLUP) was used to calculate GEBV for heat tolerance related to milk, fat and protein yield. GEBV for heat tolerance is the decline in milk, fat and protein when the environmental THI exceeds the threshold of 60 (e.g. temperature of 22°C and relative humidity of 45%). Heat tolerance GEBV were found to be unfavourably correlated to Australian Breeding Values for production traits, and favourably correlated to fertility traits (Nguyen *et al.*, 2016).

## Validation of heat tolerance breeding value

An experiment was conducted to validate HT GEBV. In a study conducted by Garner *et al.* (2016), 390 first lactation Holstein heifers were genotyped and GEBV for heat tolerance were predicted using the equation developed by Nguyen *et al.* (2016). The 24 animals with the highest predicted GEBV for most heat tolerant and the 24 animals predicted to be most heat susceptible were selected for the trial. The difference between the means of GEBV of these two groups was 2 standard deviations. The 48 cows were randomly assigned to controlled-climate chambers for a 4 day heat challenge. Daily temperatures and relative humidity inside the chambers were cycled to approximate diurnal patterns which ranged from 23.3 to 31.6°C (26.3°C mean) and from 42.2 to 71.2% relative humidity (55.2% mean) (THI = 71.6 to 82.1, 75.4 mean). The predicted heat tolerant group significantly declined less in milk ($P$<0.05, Figure 2a), fat and protein yield (Garner *et al.*, 2016), and had lower core temperature (both rectal and intra-vaginal, $P$<0.05, Figure 2b) during the simulated 4 day heat wave event, than the predicted heat susceptible group. The results indicate that heat tolerance GEBV can be reliably used to distinguish heat tolerant and heat susceptible animals.

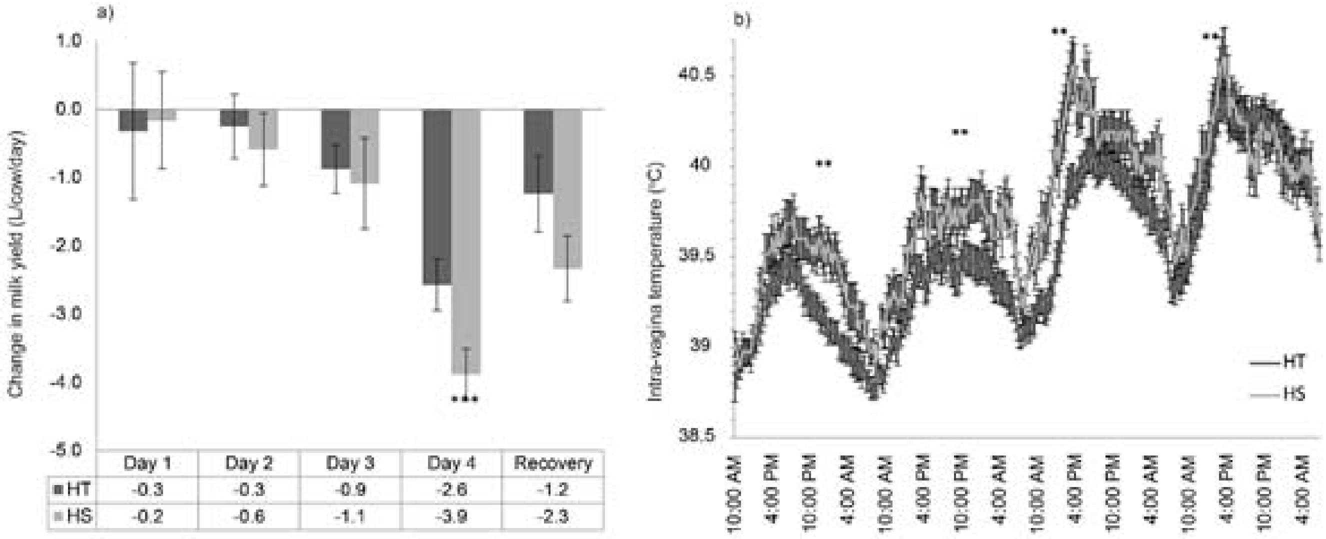


*Figure 2. a) Changes from the baseline in mean daily milk yield for cows predicted to be heat tolerant or heat susceptible; b) Intravaginal temperature for cows predicted to be heat tolerant (HT) or heat susceptible (HS) cows over the four days of heat challenge (**P<0.01, ***P<0.001).*

## Implementation of heat tolerance breeding value

Consultations with the Australian dairy industry indicated that HT GEBV needed to be expressed as a percentage which has the advantage of being free of THI units and effectively becomes a ranking. To do this, we first converted the HT GEBV, that is the decline in milk, fat and protein per unit increase of THI, to the decline in Australian dollars per unit increase of THI. We used the economic weightings of milk, fat and protein as per Byrne *et al.* (2016) for this purpose. We then standardised these values to have a mean of 100 and a standard deviation of 5 units (i.e. consistent with the presentation of other breeding values in the Australian dairy industry). These are called heat tolerance breeding value or Australian Genomic Breeding Values for heat tolerance (HT ABVg). For example, a bull with a HT ABVg of 105 has daughters that are more heat tolerant than daughters from an average bull. A bull with a HT ABVg of 95 means his daughters are less heat tolerant than the average bull.

In the Australian population of dairy cattle, HT ABVg ranged from 84 to 112 (-4SD to +3SD) in Holsteins and 86 to 117 (-3SD to +4SD) in Jerseys (Figure 3a).

To estimate the level of confidence of individual HT ABVg (i.e. how close HT ABVg the true genetic merit, or reliability), a cohort of 497 Holstein sires born in and after 2006, and 183 Jersey sires born in and after 2007 were used as validation populations. These animals and their daughters were not included in the reference sets. The reliability for the HT ABVg was assumed to be equivalent to the reliability of HT on protein yield, which is similar to the approach used by DataGene to obtain the reliability of Australian Selection Index (because protein has a greater economic value than milk and fat yield) (Nguyen *et al.*, 2017a).

Reliability is measured on a scale of 0 to 100%, with 0 being “no confidence” and 100% being “absolute confidence”. The reliability of HT ABVg in genotyped Holstein bulls with no daughters in the reference set ranged from 16% to 54%, had a mean of 38% and a standard deviation of 7%. In Jerseys, the reliability of HT ABVg ranged from 15% to 54%, had a mean of 38% and a standard deviation of 9% (Figure 3b). Although the size of the reference population of Jerseys is much smaller than that of Holsteins, a similar average reliability was achieved, probably due to the smaller effective population size in Jerseys (Hayes *et al.*, 2009). The reliability of HT ABVg is moderate and comparable to that of other economically important traits such as feed saved. Feed saved is the breeding value that allows farmers to breed dairy cows that produce the same amount of milk from less feed, due to lower maintenance requirements, feed saved has a mean reliability of 37% in genotyped Holsteins bulls with no daughters (Pryce *et al.*, 2015). Although this level of reliability enables genetic gain to be made for HT, it is desirable to improve the reliability further by increasing the size of the reference population. In this regard, the Genomic Information Nucleus (Ginfo) which includes herds with high quality phenotype recording, has been established in Australia (Pryce *et al.*, 2016). Our experience shows that the inclusion of Ginfo cows in the reference populations increases reliabilities of young genotyped bulls by between 5% and 7% for Holsteins and by between 2% and 3% for Jerseys, depending on traits (Pryce *et al.*, 2016). For HT, adding 4,711 Holstein and 3,153 Jersey Ginfo cows in the corresponding reference populations has improved reliability by 3% and 6%, respectively

(Nguyen *et al.*, 2017b). As the size of the Ginfo reference population is projected to increase over time, the reliability of HT ABVg and many other traits are expected to improve.

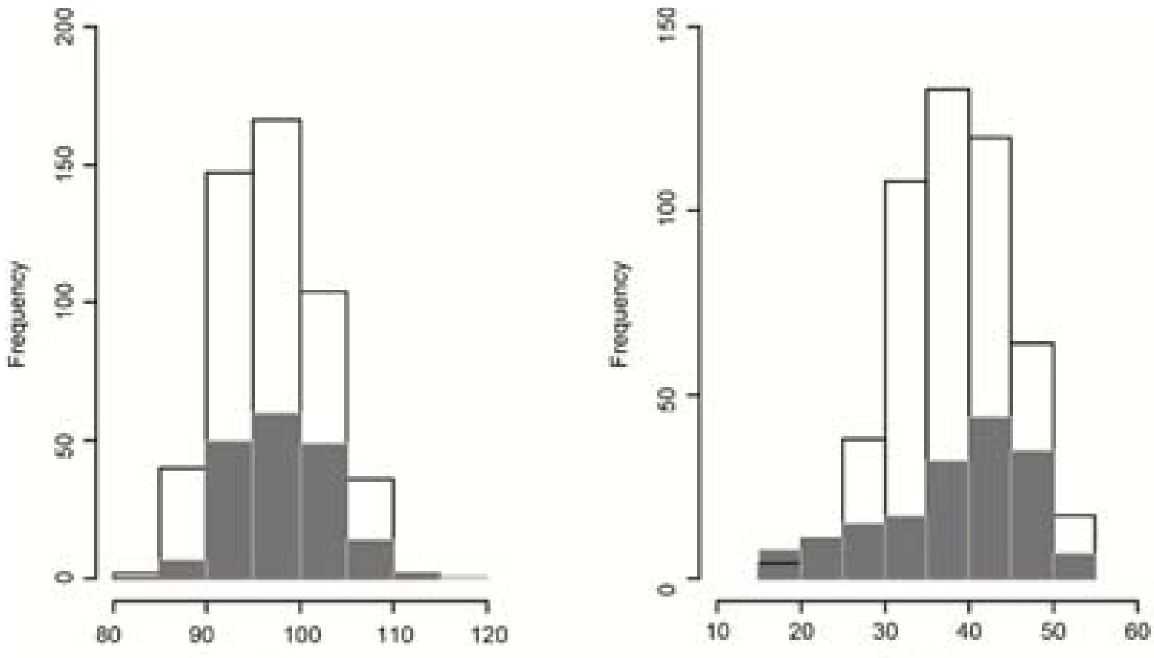


*Figure 3. (a) Distribution of Australian genomic breeding values for heat tolerance in 497 Holstein (white bars) and 183 Jersey (gray bars) bulls without daughters in the reference; (b) corresponding reliability.*

Genetic trends for both Holsteins and Jerseys show a slight decline in heat tolerance over time (Figure 4). This is expected given the correlation of heat tolerance with milk production is unfavourable (Nguyen *et al.*, 2016). Between 1990 and 2011, HT ABVg declined at a rate of 0.3% per year in both Holsteins and Jerseys. This indicates that herds in a warmer climate should take steps to prevent a further decline in heat tolerance. The best way to achieve this is to include heat tolerance in current selection indices such as the Balanced Performance Index so that heat tolerance can be improved simultaneously with other economically important production traits.

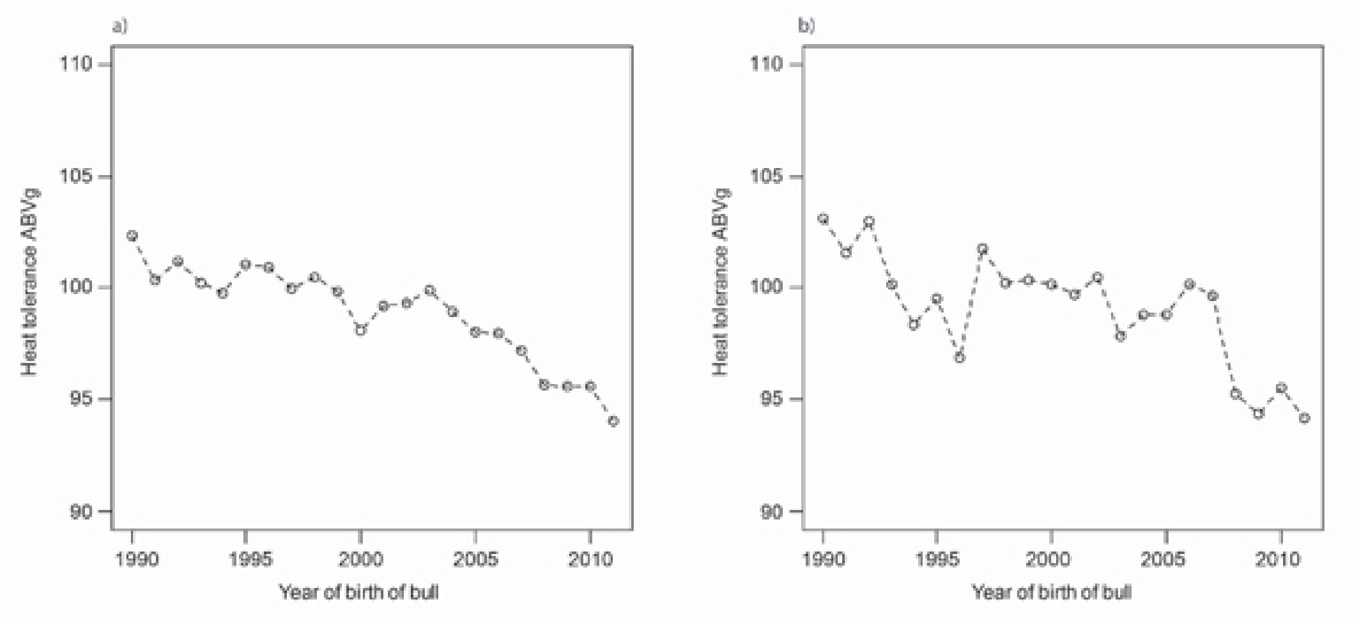


*Figure 4. Genetic trend of ABVg for heat tolerance in a) 2,665 Holstein and b) 641 Jersey bulls born in and after 1990.*

## Conclusions and future directions

We have described the road map which led to the implementation of a new breeding value for heat tolerance in Holstein and Jersey cattle in Australia. This is a genomic only breeding value, derived from merging herd test production data with relevant weather data to identify reduced productivity while under heat stress in a large population of genotyped cows and bulls. The breeding value was validated by using both cross and empirical validations. Although the mean reliability of this new trait is moderate, it is expected that this will improve as the reference populations are expanded. The heat tolerance breeding value was released in December 2017.

We plan to also develop a conventional breeding value for HT for Holsteins, Jerseys and other breeds. This will provide an opportunity for herds with good test records to establish a HT breeding value for cows in their herd. We also aim to evaluate other predictors of heat tolerance, for example changes in mid-infrared spectra profiles of milk during heat stress periods. Since Australia has a wide range of climate conditions, understanding the magnitude of genotype by environmental interactions will also be important. Impacts of heat stress on health and fertility also need to be investigated to enable a better understanding of the effects of HT on overall performance of animals and net returns. Selection for improved heat tolerance will permit the selection of more resilient animals and is expected to contribute to a more profitable dairy industry into the future.

## Acknowledgements

The studies on development and validation of HT GEBV were funded by the Australian Department of Agriculture and Water Resources. The work on improvement of reliabilities of heat tolerance genomic breeding values were funded by the DairyBio program, which is co-funded by the Department of Economic Development, Jobs, Transports and Resources, and Dairy Australia. The authors would like to thank DataGene for providing production and genotype data. We thank Dr. Brad Hine and Dr. Sonja Dominik for useful comments and suggestions which greatly improve the manuscript.

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