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

Climate, Weather and Water Services for Livestock Industries

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Livestock industry researchers and service developers often use climate, weather and water data to understand and predict the impact of environmental conditions on animals (Barry et al., 2017). However, the wide range of data services currently available can be confusing and at times misleading, resulting in less than optimal outcomes. This chapter looks to shed some light on the range of weather and climate services available with the aim of enabling researchers and developers to deliver value to their industries. It provides background on how such services are created, some key technical considerations, and a list of currently available services from the Bureau of Meteorology, CSIRO and other sources.

Genetic sensitivity of beef cattle to environmental variation

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Unravelling genetic sensitivity of beef cattle in relation to environmental variation is important as our current knowledge on this topic is limited, increasing the risk that beef herds move towards losing adaptability and efficiency due to a negative correlated response to selection for increased productivity. Genetic sensitivity to environmental variation can be investigated in different ways in animal breeding programs. Here, two strategies are discussed: i) selection based on a reaction norm (a response curve of each genotype to a range of environmental changes); and ii) selection for reduced environmental variance or increased homogeneity of production. Both strategies can be used to deal with sensitivity to different factors of environmental variation, including heat stress. Possible consequences of selection for reduced environmental sensitivity are considered. Finally, some results are presented of genomic studies focused on unravelling the genetic mechanisms associated with environmental sensitivity.

Towards breeding for heat tolerance and resilience in beef cattle

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"Heat stress" has grown in prominence as a production and welfare concern for most livestock production systems. High heat load affects animal growth, milk production, reproduction and health. As the average night temperature rises globally and locally, the dissipation of day time accumulated heat load from animals and infrastructure is reduced. This situation has been exacerbated by heat waves of increasing frequency, duration and intensity over recent decades.

The most obvious responses to high heat load and characteristic of heat stress are reduced feed intake, increased water consumption and, in cattle, panting. The reduced feed intake lowers the heat of fermentation in the rumen, and metabolic activity particularly in organs like the liver. This is an excellent coping strategy, but has serious consequences for growth and reproductive potential. This adaptation is about staying alive and in good health and while limiting other functions that impact on production until the situation normalises.

So, is the heat resilient phenotype simply an animal that keeps eating during high heat load regardless of the consequences, or the animal that copes well, preserves homeostasis and recovers quickly? In this paper we report our finding that aim to address this question.

Heat stress impacts and responses in livestock production

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The negative impacts of heat stress on livestock and associated industries are well documented. Rising temperatures associated with climate change intensify these impacts. This paper summaries various effects of heat stress on livestock including impacts on production, fertility, diet, disease and mortality. Where available the costs of heat stress are presented and reviewed. The potential of on-farm management interventions as well as breeding for reduced heat stress are discussed. Decisions on heat stress management need to be made on a case-by-case basis as they will be influenced by multiple factors including the value of the production unit, the sensitivity of production to heat stress, the frequency of heat stress events and the cost and effectiveness of the proposed management intervention.

Summer mortality in molluscs: the genetic basis for resilience and susceptibility

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Summer mortality is a phenomenon that causes mass die offs of molluscs during the summer months. Summer mortality affected molluscs include many economical important animals including; oysters, mussels, clams, scallops and abalone. The condition occurs in both natural and aquaculture environments and represents a considerable threat towards aquaculture and fisheries industries world-wide. Although sudden increases in water temperature are known contributors to summer mortality events, intrinsic factors (i.e. animal age and gametogenesis) and extrinsic factors (i.e. food availability and quality, increased salinity, decreased dissolved oxygen and the presence of pathogenic viruses and bacteria) can also play a role. Genetically driven factors are also considered to play a crucial role in susceptibility and resilience to summer mortality and these have been investigated recently using transcriptomics (i.e. broad scale patterns of gene expression). Immune, metabolic and stress response processes have commonly been found to differ between resilient and susceptible families, lines and/or populations. In addition, more complex genetic interactions such as regulatory transcription and epigenetic processes may also influence summer mortality. Determining the functional mechanisms underpinning summer mortality resilience and susceptibility will enable that knowledge to be incorporated into selective breeding/genetic improvement programs.

Addressing heat stress in pome fruit

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Cultivars recently commercialised from Australian apple and pear breeding programs have focused on quality features and disease resistance. In particular, fruit with high blush have been developed in response to market premiums. Breeding of these cultivars, which utilise traditional breeding techniques,

have not included formal assessments of extreme heat susceptibility or implications of extreme heat management strategies on quality attributes. Extreme heat can directly impact fruit through sun damage and reduction of red colour. Current and following crops can similarly be impacted by extreme heat through reduction of carbon assimilation. Several management strategies are used in commercial Australian orchards to minimise the consequences of extreme heat (spray-on protectants, evaporative cooling and over-tree netting). These strategies interact with tree processes, and by managing for extreme heat damage, reduction in quality may occur. For instance, it has been shown that over-tree netting reduced sun damage but also reduced blush coverage and intensity for a new blush pear cultivar. Extreme heat events will increase as climate change continues. In response, future breeding programs, including assessments of the implications of extreme heat on quality traits, will likely benefit growers making investment decisions. Further research into the molecular causes and interactions of sun damage and colouration would provide a pathway to breed for heat tolerant blush cultivars for sustainable production under future climates.

The challenge of improving tolerance to heat stress in livestock species

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Heat stress has numerous detrimental consequences for reproduction, health, production performance and welfare of pigs and other livestock species. To select for improved tolerance to heat stress, it is necessary to obtain phenotypes for individuals which identify genetic variation in tolerance specifically to heat stress. Performance trait phenotypes, recorded in environments considered thermally benign or consistent with a heat stress induction, have been used to infer heat stress tolerance phenotypes. However, these are indirect measures for heat tolerance which can be difficult to disentangle from other factors which contribute to variation amongst individuals in performance phenotypes. Moreover, the necessary data structures are unlikely to be available for all animals which must be evaluated. Phenotypic indicators associated with heat stress tolerance may also not be widely applicable across breeds or species, or equally relevant across different levels of exposure to heat stress. In this paper we discuss developing a direct test for heat stress tolerance based on assays for cell death and/or an *in-vitro* induction of a cellular response in heat shock protein 70 (HSP70). Using blood samples from 20 grower pigs obtained before a heat stress event imposed using climate controlled facilities, we demonstrated a moderate correlation (-0.49) between HSP70 response and the respiration rate response of pigs to increasing ambient temperature. However, ranking of animals for the HSP70 response was not consistent when retested using samples taken from the same animals in a heat stressed state. More work is required to establish whether *in-vitro* tests could play a role in providing phenotypes which enable selection for improved tolerance to heat stress.

A tool to breed for heat tolerant dairy cattle

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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.

Turning the heat up on independent culling in crop breeding

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Most grain crops are sensitive to heat stress during anthesis which causes substantial reductions in grain yield, and heat stress tolerance (HST) is therefore an important trait for selection in crop breeding programmes during the 21st century. We stochastically modelled breeding for flowering time, disease resistance, stem strength, and grain yield in a self-pollinating grain crop over the next 60 years, assuming 3-year selection cycles and 1,000 progeny per cycle, with or without priority selection for HST, and with moderate or high selection intensity (10% or 4% selection proportion). HST is measured at 30 °C during anthesis (HST30), and is assumed to be moderately heritable (h2 = 0.3). Genetic progress in a traditional crop breeding programme with independent culling on phenotypic values of individual traits was compared to progress under index selection and optimal contributions selection (OCS) on a BLUP-based economic index. In all three breeding strategies, near-homozygous lines were formed by rapid single-seed descent and selection occurred on S5-derived lines. Priority was given to selection on HST30 to match rising ambient temperatures of +4 °C during the experiment. At 60 years, all breeding strategies achieved the HST30 target of +4 units, but economic index was lowest in the traditional breeding programme (2.27-fold), intermediate in index selection (2.57-fold) and highest in OCS (2.81-fold) under moderate selection intensity. Grain yield rose from 1.50 to 3.38 t ha- 1 in OCS compared to 2.88 t ha- 1 in the traditional strategy. Without selection for HST30, grain yields under all scenarios reached a maximum of 2.30 t ha-1 and began falling around 2060, despite continued investment in breeding for yield. Independent culling on phenotype was the least effective strategy to breed for HST and grain yield during 60 years of global warming.

Breeding for reduced seasonal infertility and reduced response to heat stress in sows and boars

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This paper describes the impact of heat and seasonal stressors on the reproductive performance of pigs, management strategies to alleviate this impact and the opportunity to breed for pigs with increased ability to cope with seasonal stressors. The climate in Australia has become hotter. Currently, in Corowa NSW, there are about 40 days with a maximum temperature of above 35 °C during the year. This is a challenge for the pig industry due to pigs' limited ability to regulate their body temperature. In sows

and boars, heat stress has been identified as a factor contributing to reduction in reproductive performance over the summer/autumn period, known as seasonal infertility. Seasonal infertility is also due to changes in photoperiod and may be alleviated or elevated by multiple stressors such as heat stress, social stress or handling stress. Pig producers implement management strategies to alleviate the impact of heat stress on seasonal infertility. However, these management strategies may not eliminate all heat stress experienced by pigs. Therefore, selection for increased heat tolerance and reduced seasonal infertility of pigs will improve welfare and productivity of pigs. Genetic strategies require traits that describe seasonal infertility in boars and sows, that are of economic importance and that have genetic variation. Evidence for genetic variation in farrowing rate in response to ambient temperature (Bloemhof et al., 2008) and in response to ambient temperature and change in daylight (Sevillano et al., 2016) have been found. Despite the prominent role of farrowing rate to quantify seasonal infertility, other sow and boar traits to describe heat stress and seasonal infertility also have a genetic basis. A range of traits recorded in sows and boars should be explored to enable the development of selection strategies to reduce heat stress and/or season infertility in pigs.