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Research Paper

Pig ear skin temperature and feed efficiency: Using the phase space to estimate thermoregulatory effort

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Mammalian skin temperature is often used as an indicator of health status but has also been used in animal production as a proxy measure for thermoregulatory effort or energy wastage. An animal with a higher skin temperature may also have a lower feed efficiency. With advances in technology it is now feasible to continuously record temperatures of livestock over protracted periods of time. In this study, the ear skin pig temperature was related to feed efficiency using phase space diagram methodology. Fourteen Landrace finishers (all male) housed in one pen over a week at relatively high temperatures (average temperature throughout the experiment 27 °C) were supervised. The date, time and amount of feed consumed per individual animals was monitored via an electronic feeding station. The number of visits to the feeding station was used as an indicator of physical locomotor activity. Each animal was weighed at the beginning and at the end of the experiment to calculate their feed efficiency. The areas of the phase space diagrams of skin temperatures were used to quantify the variability of the time temperature series. Two areas in the phase space were correlated with feed efficiency ($r = 0.77$) and physical locomotor activity ($r = 0.53$). An index was developed that includes both areas, which increased the correlation between the variability of ear skin temperature and feed efficiency to $r = 0.85$. This methodology could be used to help categorise pigs in terms of feed efficiency for rapid phenotyping.

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Nomenclature

A1	Phase space area covered by 1% furthest from the centroid
A100	Phase space area covered by 100%
A61	Phase space area covered by 61% furthest from the centroid
A95.5	Phase space area covered by 95.5% furthest from the centroid
D	Dark
FE	Feed efficiency
Hi	High feed efficiency
IndA	Index based on phase space areas
IR	Infra-red
k	Time index
L	Light
Lo	Low feed efficiency
Mi	Middle feed efficiency
n	Number of recording samples
N	Phase space dimension
r	Correlation coefficient
RFID	Radio-frequency identification
RH	Relative humidity
SD	Standard deviation
T	Temperature
Td	Dry bulb temperature
t_d	Time delays
THI	Temperature-humidity index
Tw	Wet bulb temperature
Δ	Phase space time step
τ	Data acquisition interval

1. Introduction

The skin temperature of mammals can be an indicator of health status since stressed or diseased states will tend to cause hyperthermia (Loughmiller et al., 2001), but less is known about the relationship between skin temperature and thermoregulatory effort or feed efficiency. Exercise, eating, and even psychological stress can cause short term hyperthermia, changing the thermoregulatory set-point under normal, non-disease conditions (Grant, 1950). In recent years, advances in technology have produced a growing number of electronic devices for farm animals that can provide more detailed data about diurnal variation in body temperature (Langer & Fietz, 2014), including deep body implants, subcutaneous chips and infra-red (IR) thermographers (Soerensen & Pedersen, 2015). Specifically, Andersen, Jørgensen, Dybkjær, and Jørgensen (2008) demonstrated for pigs that continuous monitoring of ear skin temperature using small data loggers can give indications of thermoregulatory effort.

Feed efficiency is one of the most important determinants of animal productivity. Animals with a higher deep body temperature will use more energy to produce metabolic heat, at the expense of productivity (Britt, Thomas, Speer, & Hall, 2003; Herd & Arthur, 2009). Lower physical activity associated with reduced energy expenditure improves efficiency in pigs (Meunier-Salaün et al., 2014). Labussière, Dubois, van Milgen, and Noblet (2013) found that partitioning heat production in growing pigs can help to calculate efficiency, where heat production includes physical activity, the thermal effect of feed and basal metabolism. In cows, one study attempted to relate skin temperature with residual feed intake (DiGiacomo et al., 2014), finding that more efficient cows have lower skin temperatures than inefficient ones. Skin temperature was measured with IR technology to calculate individual thermoregulatory ability, which in turn is related to feed efficiency, although the precision of the technique varies with environmental temperature.

The thermoregulatory response of animals is influenced by environmental conditions (Wathes et al., 1994), such that hot climates can seriously limit pig production and performance. The Ministry of Agriculture in Spain suggests that pigs be fattened at a temperature between 15 and 23 °C (25–150 kg live weight). In southern Europe, hot and dry summers make it difficult to maintain this temperature in commercial feedlots (Lucas, Randall, & Meneses, 2000). Several indexes have been defined that combine the effect of temperature and relative humidity, adjusted for pigs of different live weights (Lucas et al., 2000). More studies are needed that measure individual temperature continuously and simultaneously in large groups, in combination with environmental and production data, such as the number of visits to feeding stations (Casey, 2003).

Once skin temperature data has been generated, it has to be processed in order to provide real time information to farmers to help them make decisions about how to control the thermal environment. One approach is to study the time series of a variable using new tools, such as the chaotic analysis of time series and phase spaces (or phase graphs); its potential to display the behaviour of dynamic systems of temperature has been demonstrated (Correa et al., 2014; Jiménez-Ariza et al., 2014). To the best of our knowledge, this method is not being used extensively in pig production, although Villarroel, Barreiro, Kettlewell, Farish, and Mitchell (2011) demonstrated its usefulness as a measurement of heat stress during pig transport. In this study we analysed how the phase space of ear skin temperature is related to feed efficiency and growth.

2. Materials and methods

2.1. *Animals*

Between June 19th and 26th (2017), 14 Landrace finishers (all male) were monitored in one pen (15 m^2; Fig. 1) on a breeding farm in Villatobas, Castilla-La Mancha, Spain (39°54′02.7″N 3°17′31.4″W) belonging to Hendrix Genetics, Boxmeer, The Netherlands. The initial animal density was 56.6 kg m^{-2} Environmental temperature was controlled automatically by an air cooling system (RN 12, Exafan, Spain). Extractor fans removed the hot air from the boxes when the temperature reached a set point (20 °C + 4.0 °C); hot outside air was drawn through the cooling units (wet surface of cellulose pad) to reduce temperature and increase humidity in the pens. A specific temperature sensor to control the cooling system was located 2 m above the central point of the room (total of six