Preliminary research shows potential for using proximal infrared technology for livestock monitoring and phenotyping

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Abstract

Two scoping studies have been undertaken recently investigating the potential application of infrared technology for phenotyping several different traits of beef cattle. These studies include the potential for non-invasive analysis of hair to discriminate classes of cattle (O'Neill et al. 2017) and analysis of beef through skin (Roberts et al. 2017). Infrared technology was used to collect spectra information in two different studies from hair and meat in a laboratory setting. Data was analysed using principal component analysis (PCA) and partial least squares discriminant analysis (PLS-DA) for classification. In each example, leave-one-out cross validation was applied once classification models were developed. Results from both studies were positive, with successful classification rates of muscle type and cattle class. This preliminary research supports continued investigation of if and how NIR may be developed as a versatile in-field beef cattle phenotyping sensor.

Introduction

Beef production in Northern Australia is complex with a key attribute of irregular husbandry and human and cattle interactions (Bertolussi et al. 2005). The extensive nature of these systems demands low cost, intervention and labour inputs. Due to the limited observation of livestock, the development and implementation of precision livestock technologies designed to support this has great potential. The last decade has seen a rise in the development of precision livestock management technologies. However, precision livestock farming in extensive grazing production systems has been slow. Hocquette et al. (2012) highlighted to increase uptake of precision livestock management methods, cheap, rapid and reliable phenotype collection spanning across the supply chain is required.

As defined by Greenwood et al. (2016), animal phonemics refers to "the next generation of animal trait measurement, including methodologies and equipment used to acquire data on traits, and computational approaches required to turn data into phenotypic information". The development of animal phonemics is considered promising for improving the efficiency of livestock at pasture (Greenwood et al. 2016).

A common inefficiency of Northern Australian cattle production is reproduction rates. Reproduction efficiency is considered complex and difficult to measure in commercial, extensive pasture production systems as it is the result of multiple components which may or may not be correlated (Greenwood et al. 2016). Influences include those related to physiology, infectious diseases, climate, nutrition and genetics (Burns et al. 2010). A survey of 15 Northern Territory breeders found a mean of 75% of maiden heifers conceived, yet approximately 20% lost their calves before weaning (Schatz, 2012). Without clear knowledge of herd composition (I.e. cows and calves), it is difficult to determine where reproductive inefficiencies are the largest; with key industry losses identified throughout the reproductive cycle including point of conception, during pregnancy and calf survival to weaning (Burns, et al. 2010).

Understanding herd dynamics can be useful for improving the management of feed, replacement females, cattle sales, overall productivity and husbandry related to specific cattle classes. Inefficiencies in production may be more easily identified if the numbers of animals in each class were known. For example, knowing calf numbers at various times of the year could provide insight on reproductive efficiency pre- and post- parturition.

Together with considering issues related to production efficiency, is the consideration of a product which meets consumer demand. There can be large variation in the quality of beef products. Post farm gate, emphasis on meat quality and traceability is growing with consumer demands increasing for good eating quality of animal products (Grunert, 2006). The high variability of beef palatability is a contributing factor of consumer dissatisfaction (Legrand et al. 2013). In order to address this issue in Australia, MLA has developed a grading scheme, Meat Standards Australia (MSA) which is used to predict the meat quality (Legrand et al. 2013). However, product quality and consistency continues to influence consumer choice.

The two issues highlighted appear to be quite different. Despite this, a single technology has been identified as having potential to address both (O'Neill et al. 2017, Roberts et al. 2017). More advanced phenotyping techniques, including those related to reproductive performance could see fundamental advances to livestock production (Greenwood and Bell 2014; Greenwood et al. 2014; Greenwood et al. 2016). This paper explores two scoping studies addressing the potential of this one technology, near infrared (NIR) spectroscopy, to phenotype cattle traits related to two very different issues of beef production in Australia.

The use of spectroscopy for animals and their products

NIR spectroscopy has been utilised for classification and measurement of agricultural commodities since the 1960s, with increasing expansion in recent years (Roberts et al. 2017). This expansion can be attributed to fast data collection and analysis, relatively low cost and the ability to assess many attributes simultaneously (Dufor, 2008; Osborne et al. 1993). As infrared light can penetrate living tissue, NIR spectroscopy has the potential to analyse traits in live animals and humans (Zamora-Rojas et al. 2013; Azizan et al. 2008; Bashkatov et al. 2005a; Bashkatov et al. 2005b; Jacques, 2013). Two areas of application include hair and meat analysis.

NIR analysis of hair has been used to identify and classify between and within mammal species (Hutchinson et al. 1975; Gates, 1980; da Silva et al. 2003; Bortolot & Prater, 2009). Bortolot and Prater (2009) demonstrated inter species identification using hyperspectral analysis in a rangeland situation. An important consideration for the success of spectroscopic analysis is the influence of sample location on an animal and sensor geometry (Hutchinson et al. 1975; Gates, 1980). While, animal identification is possible, there is limited literature on the potential for discerning phenotypic traits within a herd of cattle.

Quantitative and qualitative meat analysis using NIR spectroscopy has been demonstrated as an easy and quick tool for carcass and product grading (Prieto et al. 2009; Zamora-Rojas et al, 2013; Prevolnik et al. 2004). However, use for live cattle assessment has previously been reported to be complicated by the complex structure and components of the skin (Zamora-Rojas et al. 2013; Ding et al. 2005; Renaudeau et al. 2006).

Scoping study one: Phenotyping beef cattle class and sex

The characteristics of an animal's hair has played a key role fitness evolution of cattle (O'Neill et al. 2010). It has long been demonstrated that hair holds information on an animal's genotype (DNA) (Troy et al. 2001) and their environment. For example, cortisol can be measured in hair to get an indication of stress (Moya et al. 2013).

O'Neill et al. (2017) presents preliminary research on the use of NIR spectroscopy for classifying cows, calves and calf sex. Tail hair samples from Brahman cows and their calves were obtained grazed at Belmont Research Station in north-eastern Australia. Cow ages ranged between 2 and 12 years and calves ranged from 18-29 weeks old.

The hair spectra was measured with a Thermo Scientific Antaris FT-NIR Analyzer (Thermo Fisher, Madison, USA) in the NIR region (680-2500 nm) (O'Neill et al. 2017). Multivariate analysis software The Unscrambler X (CAMO AS, version 10.3, Oslo, Norway) was used for data analysis. Spectra were analysed using principal component analysis (PCA) to explore the relationship between the samples and to identify any outliers (O'Neill et al. 2017). Furthermore, partial least squares discriminant analysis (PLS-DA) regression discrimination models for the cattle hair were developed (O'Neill et al. 2017). The threshold for cattle categories was estimated using baysian statistics with the predicted values assumed to follow a distribution similar to what is expected for future samples (Brereton, 2003, 2007; Naes et al.

2002, cited in O'Neill et al. 2017). The development of the model for calf sex followed the same process (O'Neill et al. 2017).

The eigenvectors for the first two principal components were investigated in order to identify specific regions in the NIR spectra that explain the separation between samples. The results are shown in Figure 1. Key areas identified by O'Neill et al. (2017) were at 1400 and 1900 nm which are related to C-H combinations and O-H stretch overtones, associated with aromatic compounds (Workman and Weyer, 2008). The classification model was successful with correct classification rates of 92% for cows and 100% for calves (O'Neill et al. 2017).

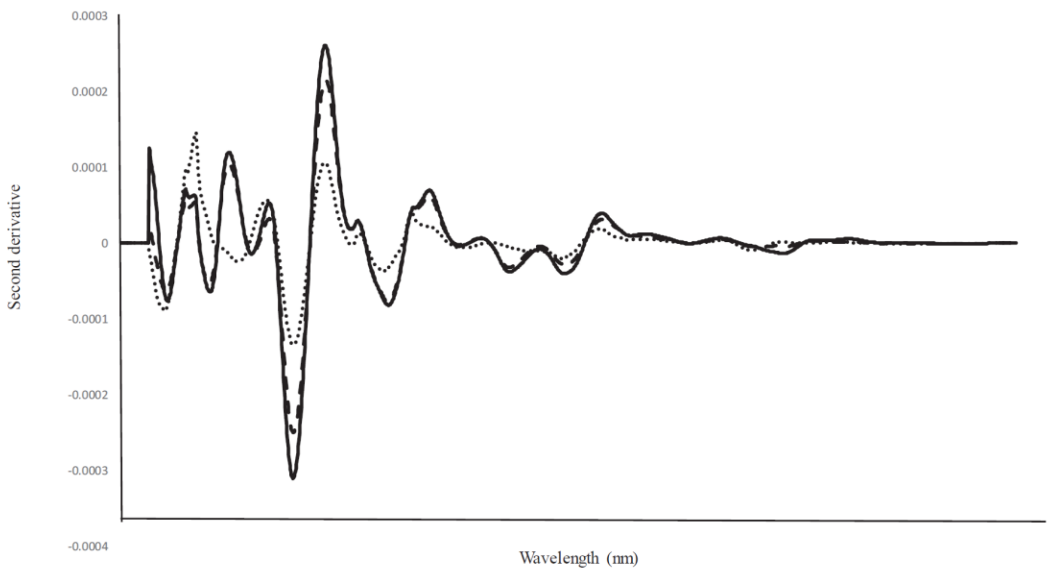

Figure 1. Second derivative mean NIR spectra of tail hair samples from different origins (calf - - -; black hair cow ……; brown haired cow ___) Adapted from O'Neill et al. (2017).

Near infrared spectroscopy provided valuable information for distinguishing the cattle class (cow or calf) and the sex of calves in the preliminary investigation (O'Neill et al. 2017). Discriminant analysis along with chemometrics has the potential harness the capability of NIR as a non-invasive tool for cattle categorisation (O'Neill et al. 2017). There is also potential for type of data collection and analysis beyond cow and calf identification towards animal associations related to genetic, nutrition and health status (O'Neill et al. 2017).

Scoping study 2: Identification of meat traits

The optical properties of commercial beef meat cuts (Rump, *Gluteous medius*; and T-bone steak, *Semitendinosus* and *Semimembranosus*) with subcutaneous fat present were analysed with and without the presence of skin. Five combinations of the tissue and skin were analysed using a FT NIR instrument (Antaris II, Thermo, USA) with the wavelength region of 700-2500nm.

The spectra obtained in this scoping study used the same chemometric analysis techniques as for the cattle classification. This included PCA with leave-one out cross validation and PLS-DA, with the models defined by the prediction residual error sum of squares (PRESS) function to avoid overfitting (Roberts et al. 2017).

The second derivative of the average NIR spectrum of the skin, muscle, fat, skin plus fat and skin plus muscle were evident at several wave numbers (Roberts et al. 2017). Key differences in the spectra were identified at wavenumbers known to correspond to moisture, protein, cartilage and lipids (Roberts et al. 2017). It was concluded that absorbance differences could have been related to different ratios of protein and collagen (Roberts et al. 2017).

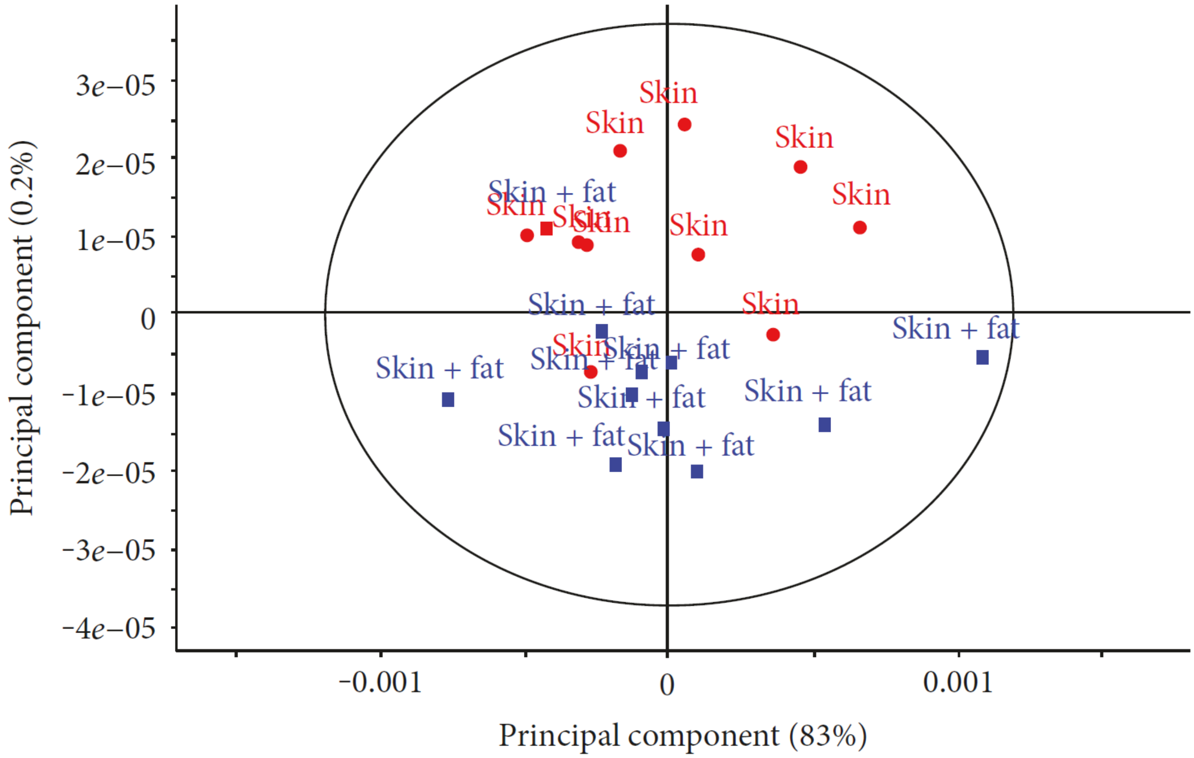

Figure 2. An example of the PCA results from the meat spectral analysis, a score plot of fat and skin plus fat in the meat samples analyses using near infrared spectroscopy. Adapted from Roberts et al. (2017).

The PCA results presented in Figure 2 highlight clear differences between the loadings the first and second principal components, which indicated different spectral information could be linked with different tissue constituents (Roberts et al., 2017). Correct classification of muscle type, fat, skin and the combinations of each was between 60-70% (Roberts et al. 2017), indicating that the NIR method used in this research can be used to distinguish different tissues through beef skin. Penetration of light within biological tissues is typically 10mm or longer (Murray and Cowe, 2004) and it appears in this study, the light penetration from the NIR method used was exceeding skin depth and detecting traits of underlying tissue.

Conclusion

Spectroscopy combined with chemometric analysis techniques, including PCA, has proven to be versatile for providing valuable information related to key phenotypic traits in several biological examples. This includes the classification of cattle (cow or calf) and the sex of calves from hair samples and muscle type through hide. These studies were completed using destructive hair and meat samples, however there is potential to collect spectral data of this nature non-invasively from the live animal.

The methodologies applied in the two scoping studies, NIR spectroscopy (combined with chemometric data analysis) demonstrated the versatility highlighted in the literature. This versatility, combined with the low cost per sample and the ability to non-destructively sample in the field, positions this technology well for future research in phenotyping. However, due to the preliminary nature of the research reviewed more work needs to be completed before practical recommendations for the cattle industry can be made. Further investigations into the methodology for live animal sampling, the extent to which phenotype classification in the field can be done and the potential for phenotyping other important traits are the next steps.

References

Azizian H, Kramer JKG, Heymsfield SB, Winsborough S 2008. Fourier transform near infrared spectroscopy: a newly developed, non-invasive method to measure body fat non-invasive body fat content measurement using FT-NIR, Lipids. 43: 97–103.

Bashkatov AN, Genina EA, Kochubey VI, Tuchin VV 2005. Optical properties of human skin, subcutaneous and mucous tissues in the wavelength range from 400 to 2000 nm, Journal of Physics D: Applied Physics 38: 2543–2555.

Bashkatov AN, Genina EA, Kochubey VI, Tuchin VV, 2005. Optical properties of the subcutaneous adipose tissue in the spectral range 400–2500 nm. Optics and Spectroscopy 99(5): 836–842.

Jacques SL 2013. Optical properties of biological tissues: a review, Physics in Medicine and Biology 58: R37– R61.

Bortolot ZJ, Prater PE 2009. A first assessment of the use of high spatial resolution hyperspectral imagery in discriminating among animal species, and between animals and their surroundings. Biosystems Engineering 102: 379–384.

Brereton RG 2003. Chemometrics: Data analysis for the laboratory and chemical plant. Chichester, UK: John Wiley & Sons, Ltd.

Brereton RG 2007. Applied chemometrics for scientists. Chichester, UK: John Wiley & Sons, Ltd.

Burns BM, Fordyce G, Holroyd RG 2010. A review of factors that impact on the capacity of beef cattle females to conceive, maintain a pregnancy and wean a calf—Implications for reproductive efficiency in northern Australia. Animal Reproduction Science 122(1): 1–22.

Ding H, Lu JQ, Jacobs KM, Hu X 2005. Determination of refractive indices of porcine skin tissues and intra lipid at eight wavelengths between 325 and 1557 nm, Journal of the Optical Society of America 22(6): 1151–1157.

Dufour E 2008. Principles of Infrared Spectroscopy, Academic Press, Elsevier Science & Technology Books, San Diego, CA, USA.

Da Silva RG, La Scala N Jr, Tonhati H 2003. Radiative properties of the skin and haircoat of cattle and other animals. Transactions of the ASAE 46: 913–918.

Gates DM 1980. Biophysical ecology. New York: Dover Publications.

Hutchinson CD, Allen TE, Spence FB 1975. Measurement of the reflectance for solar radiation of the coats of live animals. Comparative Biochemistry and Physiology 52A: 343–349.

Greenwood PL, Bell AW 2014. Consequences of nutrition during gestation, and the challenge to better understand and enhance livestock productivity and efficiency in pastoral ecosystems. Animal Production Science 54: 1109–1118. DOI: 10.1071/AN14480.

Greenwood PL, Valencia P, Overs L, Paull DR, Purvis IW 2014. New ways of measuring intake, efficiency and behaviour of grazing livestock. Animal Production Science 54: 1796–1804. DOI: 10.1071/AN14409.

Greenwood PL, Bishop-Hurley GJ, González LA, Ingham AB 2016. Development and application of a livestock phenomics platform to enhance productivity and efficiency at pasture. Animal Production Science 56(8): 1299–1311.

Grunert KG 2006. Future trends and consumer lifestyles with regard to meat consumption. Meat Science, 74: 149–160.

Moya D, Schwartzkopf-Genswein K, Veira D 2013. Standardization of a non-invasive methodology to measure cortisol in hair of beef cattle. Livestock Science 158(1): 138–144.

Murray I, Cowe I 2004. Sample preparation in near infrared spectroscopy in agriculture, American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI, USA.

Naes T, Isaksson T, Fearn T, Davies A 2002. A user-friendly guide to multivariate calibration and classification. Chichester, UK: NIR Publications.

Osborne BG, Fearn T, Davies T 1993. Practical NIR spectroscopy with applications in food and beverage analysis, in Food and Beverage Analysis. Osborne BG, Fearn T, Hindle PT eds. Longmand, Essex. Pp. 11–35.

O'Neill C, Roberts JJ, Cozzolino D 2017. Identification of beef cattle categories (cows and calves) and sex based on the near infrared reflectance spectroscopy of their tail hair, Biosystems Engineering 162: 140–146. ISSN 1537–5110, https://doi.org/10.1016/j.biosystemseng.2017.07.007.

Prevolnik M, Candek-Potokar M, Skorjank D 2004. Ability of NIR spectroscopy to predict chemical composition and quality – a review, Czech Journal of Animal Science 49: 500–510.

Prieto N, Roehe R, Lavín P, Batten G, Andrés S 2009. Application of near infrared reflectance spectroscopy to predict meat and meat products quality: a review, Meat Science 83: 175–186.

Renaudeau D, Leclercq-Smekens M, Herin M. Differences in skin characteristics in European (large white) and Carribbean (Creole) growing pigs with reference to thermoregulation. Animal Research 55: 207–219.

Roberts JJ, Motin JC, Swain D, Cozzolino D 2017. A Feasibility Study on the Potential Use of Near Infrared Reflectance Spectroscopy to Analyze Meat in Live Animals: Discrimination of Muscles, Journal of Spectroscopy. DOI: 10.1155/2017/3948708.

Schatz T 2012. Heifer Management in Northern Beef Herds 2nd edition. In: Partridge, I. (Ed.), Meat and Livestock Australia, North Sydney.

Troy CS, MacHugh DE, Bailey JF, Magee DA 2001. Genetic evidence for Near-Eastern origins of European cattle. Nature 410.

Zamora-Rojas E, Aernouts B, Garrido-Varo A, Pérez-Marín D, Guerrero-Ginel JE, Saeys W 2013. Double integrating spheres measurements for estimating optical properties of pig subcutaneous adipose tissue, Innovative Food Science and Emerging Technologies 19: 218–226.