Optimising the concentration of glycogen in lamb meat

Robin Henry Jacob

B.V.Sc. (Hons) M.A.C.V.Sc. (Epidemiology)

School of Veterinary and Biomedical Sciences

Murdoch University

Western Australia

This thesis is presented for the degree of Doctor of Philosophy of

Murdoch University

2003

Declaration

I declare that this is my own account of my research and contains as its main content work which has not been submitted for a degree at any tertiary institution.

…….

Robin Henry Jacob

Abstract

The lamb industry is actively seeking to improve the quality of lamb meat produced in Australia. Ultimate pH (pHu) is a key determinant of red meat eating quality although this measurement has not been adopted formally by the Australian lamb meat industry. Muscle glycogen concentration is a major determinant of pHu in red meat. This thesis investigates glycogen concentration in lamb muscle and the ultimate pH (pHu) of lamb meat under commercial industry conditions as well as exploring by experimentation, some of the factors that control muscle glycogen concentration in lamb muscle. The results of this work has contributed to an understanding of the significance of high pHu meat to the lamb industry and will assist with developing new management strategies for lambs that avoid low muscle glycogen concentration at the point of slaughter, thus high pHu in meat derived from lambs.

The first part of the study (Experiments 1 and 2) undertook to determine the ranges of muscle glycogen concentration and lamb meat pHu found under commercial conditions and to measure any changes in these parameters associated with consignment of lambs from farm to abattoir and lairage at abattoirs. This study utilised a new biopsy technique that allowed muscle collection from lambs on farm. Some 16 different consignments of lambs and 3 consignments of lactating ewes were intensively monitored on farm and at abattoirs over a range of lairage times. Sensory evaluation tests were done using meat from 6 of these consignments.

The results showed there to be considerable variation between lamb consignments with some consignments having a very high and other consignments having a very low incidence of meat with a high pHu. On balance "on farm" factors were concluded to have a greater impact on muscle glycogen concentration at slaughter than "post farm gate" factors. However, there was evidence that muscle glycogen concentrations decreased during the farm curfew and transport period for some consignments so both "on farm" and "post farm gate factors" can be important. Characteristically glycogen loss occurred during the farm curfew and transport period in consignments of Merino lambs that had high muscle glycogen concentrations prior to consignment. Holding lambs in lairage caused no negative effects on muscle glycogen concentration although there was some evidence that very short lairage periods may increase meat pHu without causing a change in muscle glycogen concentration. It was concluded from these experiments that the mean muscle glycogen concentration of a group of lambs needs to be greater than 1.5 g/100g on farm in order for the pHu of lamb meat to be less than 5.7.

Subsequent to this industry study, an experiment (Experiment 3) was done to gain an understanding of muscle glycogen concentration as being an integral part of whole body glucose metabolism. This experiment investigated the effects of exercise on a range of different muscles and tissues of lambs including liver, kidney, skin and gastrointestinal tract. Interactions between glycogen concentrations in the liver and muscle with time after exercise showed that glycogen repletion occurred in the liver before muscle tissue. This effect was a unique finding and could explain in part the slow rate of glycogen repletion in muscle tissue that is characteristic for ruminants. Another major finding was an

accumulation of glycogen concentration in skin during the recovery period after exercise. It was postulated that this effect may be due to the supply of glucose to glycolytic tissues being continued even when demand for glucose in the skin was low and the capacity to store glycogen in muscle was very high.

Experiment 3 confirmed the existence of a relationship between metabolisable energy (ME) intake and glycogen repletion in muscle tissues and found a slightly different relationship between ME intake and glycogen repletion in the liver tissue of lambs. Muscle glycogen concentration did not change in fasted lambs and the rate of glycogen repletion in muscle after exercise was dependent on ME intake. Differences were observed between different muscles, particularly between *M. longissimus thoracis et lumborum* (LTL) and all other muscles, in relation to the change in glycogen concentration with time after exercise. Glycogen concentrations changed less rapidly in the LTL than other muscles. Glycogen concentration in the liver was associated negatively with time after exercise in fasted lambs and positively with time after exercise in fed lambs.

Several experiments (Experiments 4, 5 and 6) were conducted to determine the affects of different nutritional factors on muscle glycogen concentration in lambs, both on farm and after commercial slaughter. These studies showed that short term increases in ME intake will increase muscle glycogen concentration to a maximum level over a period of about 7 days (Experiment 4). Diet composition did not affect the change in muscle glycogen concentration associated with an increase in ME intake although results from this experiment (Experiment 5) were not entirely conclusive. There was evidence that the type of feeding and finishing system may influence the susceptibility of muscle glycogen

concentration to change during consignment of lambs to slaughter. Results from these experiments demonstrated that a goal for muscle glycogen concentration in lambs on farm of 1.5g/100g is quite achievable with contemporaneous management systems.

Finally this study highlighted the need for further research in a number of key areas in order that muscle glycogen concentration in lambs to be fully understood. In particular, the role of muscle glycogen turnover in relation to muscle glycogen concentration was noted as an area for which further research is warranted.

Table of Contents

List of Figures

List of Tables

List of Plates

Published and submitted conference proceedings and papers

Published Conference proceedings

(i) Jacob, RH, Pethick, DW, Masters, DG, and Milton, JTB. (2001). Changes in muscle glycogen in lambs with low levels of basal glycogen fed two levels of metabolisable energy. *Recent Advances in Animal Nutrition in Australia* **13**, 8A

(ii) Jacob, RH & Pethick, DW. (2002). Comparative changes in glycogen concentrations after exercise in muscle, liver, kidney, skin and duodenum of lambs. *Proceedings of the Nutrition Society of Australia* **26,** S274.

Submitted conference proceedings

Jacob, RH, Pethick, DW, and Masters, DG. (2003) The interaction between shearing and metabolisable energy (ME) intake for muscle glycogen concentration in lambs.

The Sixth International Symposium on the Nutrition of Herbivores. Merida, Mexico

Published papers

(i) Gardner, GE, Jacob RH, &Pethick, DW. (2001) The effect of magnesium oxide supplementation on muscle glycogen metabolism before and after exercise and at slaughter in lambs. *Australian Journal of Agricultural Research* **52**: 723-729.

(ii) Pethick, DW, Cummins, L, Gardner GE, Jacob, R., Knee, BW, McDowell, M, McIntyre, BL, Tudor, G, Walker, PJ & Warner, RD. (2000). The regulation of

glycogen level in the muscle of ruminants by nutrition. *Proceedings of the New Zealand Society of Animal Production*, **21**, 353.

Papers submitted to the Australian Journal of Experimental Agriculture

(i) The effect of commercial transport and lairage on glycogen concentration and ultimate pH of lamb meat. Jacob, RH, Pethick, DW &Chapman, H

(ii) The effect of lairage time on consumer panel sensory scores of the *M. longissimus thoracis et lumborum* for lamb meat and mutton. Jacob, RH, Walker PJ, and Pethick, DW.

(iii) The effect of finishing system on the perception of lambs meat eating quality. Pethick, DW, Davidson R, Hopkins DL, Jacob RH, D'Souza DN, Thompson JT, and Walker PJ.

Acknowledgements

Firstly I would like to thank my 2 supervisors Dr Helen Chapman and Dr. Dave Pethick. Helen introduced me to the idea of embarking on a Ph.D. project and was a tremendous help during the writing phase. Dave provided the motivation, resources and drive required to see me through. His enthusiasm and leadership has been truly inspirational.

I would like to thank Dr. Dave Masters and staff at CSIRO Livestock Industries, notably Dr. Shimin Liu and Dr. Robyn Dynes, who helped with nutritional and scientific advice for several of the experiments. Dr. Graham Gardner and Dr. John Thompson from the University of New England helped me negotiate statistical analyses using SAS. The assistance of Department of Agriculture staff under the leadership of Dr. James Skerritt was also most appreciated.

The management and staff at the different abattoirs including WAMMCO International, Hillside Meats, Fletcher International, Walshes Meats and Shark Lake Abattoir gave invaluable support and cooperation as did the farmers whose lambs were used in the experiments.

Many people helped with the experiments not the least being Mr. Malcolm Boyce, Ms. Barbara Waldoch. and Mr. Ken (Joon) Chong There were many early starts, difficult field trips and literally thousands of glycogen assays required for this thesis that would not have been possible without Malcolm, Barbara or Ken. Mr David Brockway and staff from the

Murdoch University Veterinary Farm always provided excellent research facilities and service.

The National Australia Bank gave financial support for my scholarship and Meat and Livestock Australia funded much of the experimental work. This support was very much appreciated.

I would like to thank my family Lorraine, Miles and Samuel. Somehow we managed a fair bit of change as a family during the last 3.5 years, including Lorraine having 2 hip replacements. Lastly I would like to dedicate this thesis to the memory of my father, Henry Stephen Jacob.

List of Abbreviations

a	Redness
A$	Australian dollars
acetyl CoA	Acetyl coenzyme A
AD	*M. adductor*
ADP	Adenosine diphosphate
ATP	Adenosine triphosphate
ATPase	Adenosine triphosphatase
b	Yellowness
BF	*m. biceps femoris*
C*	Psychometric colour
Ca2+	Calcium ions
cAMP	Cyclic adenosine monophosphate
CoA	Coenzyme A
[ ]	Concentration
CPK	Creatinine phosphokinase
CSIRO	Commonwealth Scientific & Industrial Organisation
DFD	Dark firm dry
DM	Dry matter
FFA	Free fatty acids
g/100g	Grams per 100 grams
GLUT	Glucose transport protein
h	Psychometric hue angle
H^+	Hydrogen ions
IS	N. infraspinatus
kg/m^2	Kilograms per square metre
K_m	Michaelis-Menton coefficient
L	Luminescence
LTL	*M. longissimus thoracis et lumborum*
m^2	Square metre
mATPase	Myofibrillar actinomysin adenosine triphosphatase
ME	Metabolisable energy
mmol	Millimoles
mol	Moles
NA	Not applicable
NAD^+	Nicotinamide adenine dinucleotide
NADH	Nicotinamide adenine dinucleotide (reduced form)
NEFA	Non-esterified fatty acids
ng/mL	Nanograms per millilitre
NST	Non shivering thermogenesis
%	Percent
PDH	Pyruvate dehydrogenase
PEP	Phosphoenolpyruvate
PFK1	Phosphofructokinase 1
PFK2	Phosphofructokinase 2
pHu	Ultimate pH
Pi	Inorganic phosphate
PK	Pyruvate kinase
PM	*M. psoas major*
RN	Rendement Napole
SEQ	Lambs eating quality
SM	*M semimembranosus*
SS	*M. subscapularis*
ST	*M. semitendinosus*
SU	M. supraspinatus
TB	*M. triceps brachii*
TM	Trade mark
TCA	Tricarboxylic acid cycle
TCA	Tricarboxylic acid cycle
TL	M. tensor fascia latae
VFA	Volatile fatty acid
VO_2 max	Maximum rate of oxygen consumption