

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

A Genetic and Economic Evaluation of Lactose in the New Zealand Dairy Industry

A thesis presented in partial fulfilment of the requirements

for the degree of

Doctor of Philosophy

in

Animal Science



Nicholas William Sneddon

2016

Abstract

Sneddon (2016). A Genetic and Economic Evaluation of Lactose in the New Zealand Dairy Industry.

PhD Thesis, Massey University, New Zealand

Milk composition in New Zealand is heavily influenced by the selection for Breeding Worth (BW) and the breed composition of the national herd. Under selection for BW a greater emphasis is placed upon protein (39% of emphasis) than fat yield (13% of emphasis) with a penalty on milk volume (14% of emphasis). The export orientated product portfolio influences the development of economic values for fat and protein in the BW, to date lactose has not been considered despite its importance in the manufacture of whole milk powder (WMP). The milk produced on farm is in deficit for lactose based on the current export product portfolio. This thesis evaluated the potential of altering New Zealand milk through the modification of the selection objective around milk lactose selection. Genetic parameters were estimated including lactose yield to construct selection objectives and indices to evaluate the effect on lactose production under a number of different product portfolio scenarios. Genetic parameters were estimated from daily and total milk records with moderate heritabilities found for both lactose yield and lactose content. The genetic correlations between lactose yield and milk volume was estimated to be 0.98, which is a potential problem as this correlation effectively gives lactose a negative economic value due to the negative value on milk volume. Using an existing industry milk processing model, the lactose deficit was estimated to be 129,000 tonnes in 2012 which is consistent with industry records. A genetic gains model developed from this thesis, combined with an existing industry model estimated that the deficit in lactose would increase by 60%, to 204,000 tonnes by

2022 if no changes were made to the current selection objective and index. Including lactose yield in the selection objective with an economic value of \$2.04, 14.7% relative emphasis within the objective, would reduce the lactose deficit by 8.7% to 194,000 tonnes. Overall the results of this thesis indicate that including lactose yield in the selection objective has the potential to modify the composition of milk to make it more suitable for the production of WMP and increase the potential for profit in the industry.

Declarations

This thesis contains no material that has been accepted for a degree or diploma by the University or any other institution. To the best of my knowledge no material previously published or written by another person has been used, except where due acknowledgement has been made in text.

This thesis has been written with chapters formatted as papers for publication. Therefore there is some repetition of chapter introductions or methods, each chapter contains a full discussion, with the final general discussion chapter providing a succinct discussion of key findings of this thesis. Each chapter has been formatted for the New Zealand Journal of Agricultural Science and each has a complete list of references. The submitted manuscripts include supervisors as co-authors, however, for each chapter I planned the study, undertook the analysis and wrote the manuscripts with directions of those co-authors.

Acknowledgements

I am firstly thankful for the guidance, encouragement and challenges provided by my supervisors Professor Nicolas Lopez-Villalobos, Dr Rebecca Hickson, Dr Steve Davis and Dr Laurence Shalloo.

Firstly to Professor Lopez-Villalobos thank you for always having a friendly smile, supportive ear when I came with a problem, for always pushing and encouraging me to find the answer myself and sharing your knowledge of animal breeding with me. To Dr Rebecca Hickson, thank you for helping me improve my scientific writing (no small task in itself) and making me think about the problems in new ways. To Dr Steve Davis your knowledge of the biochemistry of milk is always appreciated and the questions of carrot or stick. To Dr Laurence Shalloo I thank you for supporting my visit to Ireland to work with you with the processing models and your positivity when we investigated a new set of scenarios.

My thanks to Professor Dorian Garrick for his comments, suggestions, expertise and quick turn around when we needed a fresh set of eyes to look over the works of this thesis. To Una Geary my thanks for access to the processing model you developed and your input when using these models. To Professor Colin Holmes for the friendly conversations on the dairy industry in general.

The support of IVABs staff and students in particular Professor Kevin Stafford, Miss Debbie Hill, Wendy Graham (thank you for putting up with me crashing your previously quiet morning quizzes), Professor Paul Kenyon, Professor Danny Donaghy,

Dr Penny Back. To my friends Felipe, Jose, David, Alan and Lydia thank you for conversations on a myriad of topics and occasional impromptu Spanish lessons.

To LIC for supporting my research through providing data and the Pat Shannon Scholarship, Westpac Taranaki Agricultural Research Station for the Colin Holmes Dairy Scholarship, the MacMillan Brown Agricultural Research Scholarship and the F W Dry Memorial Award for their financial assistance.

To my parents and family (who number such that listing them all would take 2 pages alone) my thanks for putting up with and challenging me for the last 29 years of my life and may you all continue to do so.

But most of my thanks go to my partner Kirsty for having put up with me and being there as a sounding board for ideas for 10 years. I could not have undertaken 1/10th of this work without you there beside me through it.

“The presence of those seeking the truth is infinitely to be preferred to the presence of those who think they've found it.”

Sir Terry Pratchett, *Monstrous Regiment*

Contents

Abstract	i
Declarations	iii
Acknowledgements	iv
Contents	vi
List of Tables	viii
List of Figures	xii
List of Abbreviations	xiii
List of Appendices	xiv
Chapter 1	
General introduction	1
Chapter 2	
Literature review	9
Chapter 3	
Genetic parameters for milk components including lactose from test day records in the New Zealand dairy herd	49
Chapter 4	
Lactose demand in New Zealand and Ireland under different simulated milk product portfolios	77
Chapter 5	
Predicted Dairy Product Yields and Deficits of Lactose for Manufacturing under Differing Selection and Manufacturing Scenarios in New Zealand	105

Chapter 6

Estimates of genetic and crossbreeding parameters for milk components and potential yield of dairy products from New Zealand dairy cattle127

Chapter 7

Responses in lactose yield, lactose percentage and protein-to-protein-plus-lactose ratio from index selection in New Zealand dairy cattle147

Chapter 8

General discussion177

Appendix One201

List of Tables

Table 2.1. Genetic and phenotypic correlations between milk components.	27
Table 2.2. Reported lactose monohydrate concentrations (g/100 ml milk) for differing breeds.	29
Table 2.3. Comparison of milk payment systems in different countries (adapted from International Dairy Federation 2006) with all values expressed as New Zealand dollars.	34
Table 2.4. Economic values and expected response in milk traits achieved through selection based on Breeding Worth. NZD= New Zealand dollars.....	40
Table 3.1. Mean, standard deviations (SD), minimum and maximum for milk traits per day.....	59
Table 3.2. Estimates of variance components and heritabilities (h ²) and repeatabilities (rep) with their associated standard errors of the mean for milk production traits.	60
Table 3.3. Estimates of genetic and phenotypic correlations ¹ with standard errors of the mean for milk production traits.....	62
Table 3.4. Mean, regression coefficients of Jersey (relative to Holstein-Friesian) and heterosis Holstein-Friesian×Jersey (Het F×J) for milk traits.	64
Table 3.5. Phenotypic responses in milk traits and breed composition to selection of top 10% of cows (n=430) for different estimated breeding values (EBV).	67
Table 4.1. 2011/2012 economic values (USD) of products in the model simulation and 2010 and 2011 product values used in sensitivity analysis and production cost per product used for all years of economic calculation.....	84
Table 4.3. Baseline 2012 dairy industry production (LIC & DairyNZ 2012; CSO 2013; DCANZ 2013) and estimated future production (based on current rate of expansion for	

New Zealand (LIC & DairyNZ 2012) and Irish expansion post-quota) figures for Ireland and New Zealand.	86
Table 4.4. Proportion (%) of total milk to each product stream in initial modelling.	88
Table 4.5. Tonnes (,000) of product produced from modelling alternative scenarios for Ireland.	92
Table 4.6. Tonnes (,000) of product produced from modelling alternative scenarios for New Zealand.	93
Table 4.7. Gross revenue (millions USD) from model outputs for Irish scenarios.	95
Table 4.8. Gross revenue (millions USD) from model outputs for New Zealand scenarios.	96
Table 4.9. Costs and net revenue (millions USD) for each scenario after accounting for manufacturing costs.	97
Table 4.10. Effect of yearly variation on net revenue (millions USD) of each scenario.	98
Table 5.1. Production per cow, per hectare and across the industry for the base and after 10 years of selection for breeding worth.	112
Table 5.2. Proportions of milk used for each product under the four investigated product portfolios in study as input values for the Moorepark processing sector model (Geary et al. 2010).	115
Table 5.3. Composition of dairy products in g/100g of final product.	115
Table 5.4. Industry production of dairy products ($\times 10^3$ ton) from milk produced in the base and after 10 years of selection for breeding worth under four possible future product portfolios and change from base.	119
Table 6.1. Lactation yields of milk and milk product potentials from Holstein-Friesian (F), Jersey (J) and crossbred (FxJ) first lactation heifers and standard errors.	137

Table 6.2. Estimates of Variance components and heritabilities (h^2) with their associated standard errors of the mean for total lactation milk production traits and milk product potential.	138
Table 6.3. Estimates of genetic and phenotypic correlations and standard errors for total lactation yields of milk production traits and estimated milk product potential.....	139
Table 7.1. Economic values and relative emphasis (in brackets) for traits in Breeding Worth (BW) and different selection objectives investigated including selection for lactose yield (LY), lactose percentage (LP) and protein-to-protein-plus-lactose (P:P+L).	153
Table 7.2. Genetic (below diagonal) and phenotypic (above diagonal) correlations among traits used in investigated selection indices for breeding worth and breeding worth including either lactose yield, lactose percentage and protein-to-protein-plus-lactose ratio.	156
Table 7.3. Assumptions pertaining to the four pathways of selection, including starting population size, proportion selected, intensity of selection (i), generation interval, number of records and number of progeny (in sire proving scheme).	159
Table 7.4. Correlated responses per year in traits for the current New Zealand dairy industry selection objective (Breeding Worth) and alternative selection objectives including either lactose yield, lactose percentage or the ratio of protein-to-protein-plus-lactose.....	162
Table 7.5. Estimated milk, fat, protein and lactose production per cow, across the industry (thousands of tonnes) and the size of the required cow population based on the genetic gains derived after 10 years of selection for the current selection objective or alternative selection objectives including lactose yield, percentage and the ratio of protein-to-protein-plus-lactose.....	166

Table 7.6. Industry production of milk products (thousands of tonnes) and industry income (millions of \$US) based on genetic gains derived after 10 years of selection for current selection objective or alternative selection objectives including lactose yield, percentage and the ratio of protein-to-protein-plus-lactose. 168

Table 8.1. Yields of milk, dairy products and associated lactose deficit (,000s tonnes) under two different product portfolios after 10 years of selection for breeding worth in New Zealand. 191

List of Figures

Figure 2.1. Idealised diagram showing the changes in milk, fat, protein and lactose yields as well as the changes in the concentrations of fat, protein and lactose over the lactation adapted from Holmes et al. (2007).....	22
Figure 3.1. Correlation between (a) daily milk yield estimated breeding values (EBV) and daily lactose yield EBV; (b) daily milk yield EBV and daily lactose percentage EBV; (c) daily milk yield EBV and daily protein-to-protein-plus-lactose ratio EBV from first lactation cows in the 2011-2012 dairy season.	68
Figure 8.1. Changes in breed composition of the national herd and fat and protein concentration in milk from the New Zealand dairy industry over 26 dairy seasons (1988-2014) (LIC & DairyNZ 2014).	181

List of Abbreviations

P:P+L = Protein-to-protein-plus-lactose ratio
P:F = Protein-to-fat ratio
TMY = Total lactation milk yield
MY = Daily milk yield
TFY = Total lactation fat yield
FY = Daily fat yield
TPY = Total lactation protein yield
PY = Daily protein yield
TLY = Total lactation lactose yield
LY = Daily lactose yield
MS = Milk solids
MSY = Milk solids yield
FP = Fat percentage
PP = Protein percentage
LP = Lactose percentage
SCS = Somatic cell score calculated as $\text{Log}_2(\text{somatic cell count})$
DIM = Days in milk
F = Holstein-Friesian
J = Jersey
OT = Other breeds (Ayrshire, Brown Swiss, Guernsey, Milking Shorthorn.)
FxJ = Holstein-FriesianxJersey crossbred cows
BW = Breeding Worth
EBV = Estimated breeding values
WMP = Whole milk powder
SMP = Skim milk powder
WP = Whey powder
BMP = Butter milk powder
MPC(90) = Milk protein concentrate (90% protein)
MPSM = Moorepark processing sector model
DM = Dry matter

List of Appendices

Appendix one

Statements of contribution to doctoral thesis containing publications 201