

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.

Prediction of storage potential and firmness loss of ‘Hayward’ kiwifruit along the supply chains in India

A thesis submitted in partial fulfilment of the requirements for the degree of

Master of Food Technology

Massey University,

Albany Campus, New Zealand

Sneha Prakash Bellavi Jayashiva

February, 2012

ABSTRACT

Introduction: The ‘Hayward’ kiwifruit (*Actinidia deliciosa* (A. Chev.) C.F. Liang and A.R. Ferguson) is one the most common commercial variety grown in New Zealand. The long shelf-life of the ‘Hayward’ kiwifruit along with its inherent properties such as flavour, colour, texture and high content of vitamin C has allowed the development of New Zealand kiwifruit exports. However, the quality of the fruit can be affected by factors such as storage time and temperature along the supply chains to different markets. Temperature is one the major environmental factors influencing the quality and flesh firmness of the ‘Hayward’ kiwifruit. The softening of kiwifruit can be affected by increase in the environmental temperatures, leading to the deterioration of fruit quality. The aim of this study was to investigate changes in physiochemical parameters of kiwifruit along the supply chains to Indian markets, as well as development of predictive mathematical models for the loss of flesh firmness and storage potential of ‘Hayward’ kiwifruit along these supply chains.

Materials and Methods: The ‘Hayward’ kiwifruit grown in the regions of Bay of Plenty, New Zealand, were selected for this study. Three supply chains were identified through three local kiwifruit distributors based in India. Eighteen kiwifruit trays (six trays, each from three different grower lines) were selected for analysis along each supply chain. At each analysis point along the three supply chains, the ‘On arrival’ and ‘At departure’ quality of twenty fruits were analysed for flesh firmness (kgf), soluble solids content (%Brix) and core temperatures (°C). The flesh firmness of the fruit was measured using a penetrometer and the soluble solids content was measured using a refractometer. The core temperature of the fruit was determined using a core thermometer. The environmental temperature during storage and transportation along the supply chains were recorded using data loggers. Three fruit firmness loss models: Simple Exponential, Boltzmann and Inverse Exponential Polynomial were used to characterise the flesh firmness data collected along each supply chain. The Akaike Information Criteria (AIC) test was used to determine the most suitable model that characterised the flesh firmness loss along these supply chains. Three storage potential models: Reciprocal, Power and Reciprocal Quadratic, were fitted to the flesh firmness and core temperature data collected along each supply chain. The best model to predict the storage potential of kiwifruit was also determined by the AIC test.

Results: The flesh firmness decreased significantly ($P<0.05$) in all the grower lines along the three supply chains. The flesh firmness of kiwifruit decreased to the average level of commercial acceptability (1 kgf) within six to eight days of storage and transportation and further reductions were observed along the supply chains. The soluble solids content increased significantly ($P<0.05$) in kiwifruit belonging to the different grower lines with the variation in storage and transportation temperatures along the three supply chains. The Simple Exponential model best characterised the firmness data collected along Supply Chains 1 and 3, and the Boltzmann model was the second best model that characterised the firmness loss followed by the Inverse Exponential Polynomial model. Changes in the flesh firmness of the fruit along Supply Chain 2 were best characterised by the Boltzmann model followed by the Inverse Exponential Polynomial and Simple Exponential models. Among the three storage potential models, the Reciprocal model best fitted the data on flesh firmness and core temperature, collected in this study. The Power model was the second best storage potential model that characterised the data collected along the three supply chains. The Reciprocal Quadratic model was the least suitable model that characterised the flesh firmness and core temperature data in this study.

Conclusion: The flesh firmness and the soluble solids content of 'Hayward' kiwifruit were affected by temperature variations during storage and transportation along the three supply chains in India. The Simple Exponential model best characterised the flesh firmness data collected along Supply Chains 1 and 3 while the Boltzmann model best characterised the firmness data along Supply Chain 2. The Reciprocal model was the best model to characterise the flesh firmness and core temperature data in this study. The developed storage potential models can be used to determine the shelf-life of kiwifruit along similar supply chains to other markets.

ACKNOWLEDGEMENTS

The completion of my postgraduate studies in Food Technology at Massey University would have been impossible without the support and the help of several individuals and organizations.

First and foremost, I wish to acknowledge the financial support given by Zespri International Limited and the Ministry of Science and Technology (MSI) to conduct this project.

I am highly indebted to Dr Frank Bollen, In-Transit Fruit Conditioning Manager at Zespri International Limited, for his guidance and constant inspiration as well as for providing necessary information regarding the project. I would like to thank Alistair Mowat and Dr Greg Clark for creating an opportunity for me to work in this project. My deepest appreciation goes to Ian Stevens and his colleagues at AgFirst for training me during this study. I would also like to thank Ritesh Bhimani for his help during my stay in India.

I offer my sincerest gratitude to my supervisor, Dr. Tony Mutukumira, for his supervision, advice and guidance from the very early stage of this research. His crucial contribution and supervision has made him a backbone to this research and so to this report. Above all and most needed he provided me unflinching encouragement and support in various ways without which the completion of this project would not have been possible.

I gratefully acknowledge my co-supervisor, Alan Win, for his supervision and encouragement which helped me to complete this project. I would also like to thank him for sharing his views and ideas in moulding the project. I would like to thank Dr Daniel Walsh for helping me with the statistical analysis.

Words fail me to express my appreciation to my family whose love and persistent confidence in me have got me where I am today. I am grateful for their continuous support and help in achieving my goals and fulfilling my dreams. I would like to thank Sadia Seemeen, my best friend for her support during the research. I am extraordinarily fortunate in having Sandeep Patil as my partner. His love, support and encouragement has made this project a great success.

TABLE OF CONTENTS

ABSTRACT	i
ACKNOWLEDGEMENTS	iii
LIST OF FIGURES	vii
LIST OF TABLES	xii
LIST OF APPENDICES	xiii
ABBREVIATIONS	xv
1.0 INTRODUCTION.....	1
1.1 Main Objective	2
1.2 Specific Objectives.....	3
2.0 LITERATURE REVIEW	4
2.1 Introduction.....	4
2.2 Kiwifruit	6
2.3 Chemical composition of Green kiwifruit	9
2.4 World production and export of kiwifruit.....	13
2.5 Biological factors influencing fruit deterioration.....	17
2.5.1 Harvest maturity	17
2.5.2 Respiration	18
2.5.3 Ethylene production.....	20
2.5.4 Compositional changes	22
2.5.5 Transpiration or water loss.....	23
2.5.6 Physiological breakdown	23
2.5.7 Physical damage	25
2.5.8 Pathological breakdown.....	26
2.6 Environmental factors influencing fruit deterioration	27
2.6.1 Temperature	27
2.6.2 Relative humidity	29
2.6.3 Atmospheric composition	30
2.6.4 Ethylene	31
2.6.5 Packaging of kiwifruit	32

2.7 Transportation, handling and distribution of kiwifruit	33
2.7.1 Logistics and supply chain management	37
2.7.2 Refrigeration and cooling systems	39
2.7.3 International transportation or freighting	42
2.7.4 Temperature maintenance and monitoring of fruit during transportation	43
2.7.5 Distribution and marketing of kiwifruit in India	45
2.8 Kiwifruit softening during postharvest period	47
2.9 Prediction of kiwifruit softening using mathematical models	49
3.0 MATERIALS AND METHODOLOGY.....	53
3.1 Fruit selection.....	53
3.2 Curing of kiwifruit	53
3.3 Sorting and grading of kiwifruit at the packhouse	54
3.4 Packaging of kiwifruits into trays	55
3.5 Transportation (export) of Green kiwifruit to India	56
3.6 Identification of importers/distributors in India	56
3.7 Identification of supply chains through the distributors	57
3.8 Evaluation of identified supply chains	59
Supply Chain 1.....	59
Supply Chain 2.....	62
Supply Chain 3.....	65
3.9 Analysis of kiwifruit quality	68
3.9.1 Sampling and sample size.....	68
3.9.2 Measurement of core temperature	68
3.9.3 Measurement of flesh firmness	69
3.9.4 Measurement of soluble solids content.....	70
3.9.5 Temperature monitoring	71
4.0 STATISTICAL ANALYSIS AND MODELING.....	72
4.1 Statistical analysis	72
4.2 Modeling.....	72
4.2.1 Model fit for firmness loss	72
4.2.2 Model fit for storage potential.....	74
4.2.3 Determination of best model fit.....	75

5.0 RESULTS.....	78
5.1 Assessment of data collected along each supply chain	78
5.1.1 Supply Chain 1	78
A. Effect of time and temperature on flesh firmness of kiwifruit	78
B. Effect of time and temperature on soluble solids content (Brix) of kiwifruit	80
5.1.2 Supply Chain 2	84
A. Effect of time and temperature on flesh firmness of kiwifruit	84
B. Effect of time and temperature on soluble solids content (Brix) of kiwifruit	86
A. Effect of time and temperature on flesh firmness of kiwifruit	90
B. Effect of time and temperature on soluble solids content (Brix) of kiwifruit	92
5.2 Model Fitting	96
5.2.1 Supply Chain 1	96
A. Firmness loss models.....	96
B. Development of Storage potential models	100
C. 3D modeling to describe the effect of core temperature and SSC on the flesh firmness	104
5.2.2 Supply Chain 2	105
A. Firmness loss models.....	105
B. Development of storage potential models	109
C. 3D modeling to describe the effect of core temperature and SSC on the flesh firmness	111
5.2.3 Supply Chain 3	112
A. Firmness loss models.....	112
B. Development of storage potential models	116
C. 3D modeling to describe the effect of core temperature and SSC on the flesh firmness	121
6.0 DISCUSSION.....	123
6.1 Flesh firmness change during storage and transportation of kiwifruit	123
6.2 Changes in Soluble Solids Content during storage and transportation of kiwifruit	127
6.3 Modeling softening of kiwifruit	130
7.0 CONCLUSION.....	135
8.0 RECOMMENDATIONS	138
9.0 REFERENCES	139

LIST OF FIGURES

FIGURES		Page no.
Figure 2.1	Top: Longitudinal midsection of mature ‘Hayward’ kiwifruit. Bottom: Cross midsection of kiwifruit.....	9
Figure 2.2	Top ten kiwifruit exporting countries in year 1999 (a) and 2004 (b).....	15
Figure 2.3	Kiwifruit export earnings by New Zealand kiwifruit industry from 1989 to 2004.....	16
Figure 2.4	The pattern of changes in flesh firmness, soluble solids content of fruit at harvest and after ripening and total solids of kiwifruit monitored at six California locations in 1988 and 1989.....	18
Figure 2.5	Average respiration (CO ₂ production) and ethylene (C ₂ H ₂) production by kiwifruit subjected to mechanical injury after (a) 4 weeks (at a flesh firmness of 5.3 kgf) and (b) 8 weeks (at a flesh firmness of about 2.5 kgf) in storage at 0°C and 90% relative humidity.....	26
Figure 2.6	Softening phases of early and late harvest kiwifruit.....	48
Figure 2.7	Simple Exponential model in predicting kiwifruit softening curves...	50
Figure 2.8	Boltzmann model in predicting kiwifruit softening curves.....	51
Figure 2.9	Inverse Exponential Polynomial Model in predicting kiwifruit softening curves.....	52
Figure 3.1	(a) Compac InVision 7000 Blemish Unit installed at the Aongatete packhouse for sorting Green kiwifruit; (b) Visual inspection at the packhouse before packaging.....	54
Figure 3.2	Kiwifruit packed in single layer in cardboard tray and covered with HDPE liner.....	55
Figure 3.3	Kiwifruit tray label.....	56
Figure 3.4	Flow diagram of the three identified supply chains.....	57
Figure 3.5	Map of India showing the routes of the three identified kiwifruit supply chains.....	58

Figure 3.6	(a) Kiwifruit trays stored at Savla Food and Cold Storage Ltd.; (b) Kiwifruit displayed at Delhi retail market for purchase.....	60
Figure 3.7	Movement of kiwifruit and measurement of core temperature (CT), flesh firmness (FF) and soluble solids content (SSC) of kiwifruit along Supply Chain 1.....	61
Figure 3.8	(a) Trays of green kiwifruit stored at CJ Jain cool store; (b) Kiwifruit displayed at Mumbai retail market/vendor store.....	63
Figure 3.9	Movement of kiwifruit and measurement of core temperature (CT), flesh firmness (FF) and soluble solids content (SSC) of kiwifruit along Supply Chain 2.....	64
Figure 3.10	(a) Labelled kiwifruit trays stored at the Bangalore wholesale market (Safal market); (b) Kiwifruit displayed at the vendor store in Bangalore.....	66
Figure 3.11	Movement of kiwifruit and measurement of core temperature (CT), flesh firmness (FF) and soluble solids content (SSC) of kiwifruit along Supply Chain 3.....	67
Figure 3.12	Testo 106 core thermometer (Testo Incorporated, USA) used for measuring core temperature of kiwifruit.....	69
Figure 3.13	Fruit pressure tester/penetrometer (FT 011, Wilson, Italy) used to determine the flesh firmness of kiwifruit.....	70
Figure 3.14	Refractometer (RA-250WE, KEM, Japan) calibrated to 'zero' before measurement of SSC of kiwifruit.....	71
Figure 5.1	Effect of storage and transportation on flesh firmness (kgf) of kiwifruit belonging to the three grower lines along Supply Chain 1...	79
Figure 5.2	Effect of environmental temperature on flesh firmness (kgf) of kiwifruit belonging to the three grower lines along Supply Chain 1...	80
Figure 5.3	Changes in Brix (%SSC) of kiwifruit belonging to the three grower lines along Supply Chain 1.....	81
Figure 5.4	Effect of temperature variation (2.8-19.3°C) on Brix (%SSC) in three kiwifruit grower lines along Supply Chain 1.....	82
Figure 5.5	Effect of storage and transportation on flesh firmness (kgf) of kiwifruit belonging to the three grower lines along Supply Chain 2...	85

Figure 5.6	Effect of environmental temperature on flesh firmness (kgf) of kiwifruit belonging to the three grower lines along Supply Chain 2...	86
Figure 5.7	Changes in Brix (%SSC) of kiwifruit belonging to three grower lines along Supply Chain 2.....	87
Figure 5.8	Effect of temperature variation (3.3-26.4°C) on Brix (%SSC) in three kiwifruit grower lines along Supply Chain 2.....	88
Figure 5.9	Effect of storage and transportation on flesh firmness (kgf) of kiwifruit belonging to the three grower lines along Supply Chain 3...	91
Figure 5.10	Effect of environmental temperature on flesh firmness (kgf) of kiwifruit belonging to the three grower lines along Supply Chain 3...	92
Figure 5.11	Changes in Brix (%SSC) of kiwifruit belonging to three grower lines along Supply Chain 3.....	93
Figure 5.12	Effect of temperature variation (3.1-24.8°C) on Brix (%SSC) in three kiwifruit grower lines along Supply Chain 3.....	94
Figure 5.13	Three firmness loss models fitted to the flesh firmness data of kiwifruit obtained during storage and transportation along Supply Chain 1.....	96
Figure 5.14	Comparison of the Simple Exponential and Boltzmann models fitted to the flesh firmness data collected during storage and transportation of kiwifruit along Supply Chain 1.....	97
Figure 5.15	Comparison of the Simple Exponential and Inverse Exponential Polynomial models fitted to the flesh firmness data collected during storage and transportation of kiwifruit along Supply Chain 1.....	98
Figure 5.16	Comparison of the Boltzmann and Inverse Exponential Polynomial models fitted to the flesh firmness data collected during storage and transportation of kiwifruit along Supply Chain 1.....	99
Figure 5.17	Three non-linear models (Reciprocal, Power and Reciprocal Quadratic) fitted to the flesh firmness and core temperature data of kiwifruit collected along Supply Chain 1.....	100
Figure 5.18	Comparison of the Reciprocal and Reciprocal Quadratic models fitted to the flesh firmness and core temperature data of kiwifruit collected along Supply Chain 1.....	101

Figure 5.19	Comparison of the Reciprocal and Power models fitted to the flesh firmness and core temperature data of kiwifruit collected along Supply Chain 1.....	102
Figure 5.20	Comparison of the Power and Reciprocal Quadratic models fitted to the flesh firmness and core temperature data of kiwifruit collected along Supply Chain 1.....	103
Figure 5.21	Linear Logarithmic model fitted to the flesh firmness (kgf), Brix (%SSC) and core temperature (°C) data of kiwifruit collected along Supply Chain 1.....	105
Figure 5.22	Three firmness loss models fitted to the flesh firmness data of kiwifruit obtained during storage and transportation along Supply Chain 2.....	106
Figure 5.23	Comparison of the Boltzmann and Inverse Exponential Polynomial models fitted to the flesh firmness data collected during storage and transportation of kiwifruit along Supply Chain 2.....	106
Figure 5.24	Comparison of the Simple Exponential and Boltzmann models fitted to the flesh firmness data collected during storage and transportation of kiwifruit along Supply Chain 2.....	107
Figure 5.25	Comparison of the Simple Exponential and Inverse Exponential Polynomial models fitted to the flesh firmness data collected during storage and transportation of kiwifruit along Supply Chain 2.....	108
Figure 5.26	Two non-linear models (Reciprocal and Power) fitted to the flesh firmness and core temperature data of kiwifruit collected along Supply Chain 2.....	110
Figure 5.27	Comparison of the Reciprocal and Power models fitted to the flesh firmness and core temperature data of kiwifruit collected along Supply Chain 2.....	110
Figure 5.28	Linear Logarithmic model fitted to the flesh firmness (kgf), Brix (%SSC) and core temperature (°C) data of kiwifruit collected along Supply Chain 2.....	112
Figure 5.29	Three firmness loss models fitted to the flesh firmness data of kiwifruit obtained during storage and transportation along Supply Chain 3.....	113

Figure 5.30	Comparison of the Simple Exponential and Boltzmann models fitted to the flesh firmness data collected during storage and transportation of kiwifruit along Supply Chain 3.....	114
Figure 5.31	Comparison of the Simple Exponential and Inverse Exponential Polynomial models fitted to the flesh firmness data collected during storage and transportation of kiwifruit along Supply Chain 3.....	115
Figure 5.32	Comparison of the Boltzmann and Inverse Exponential Polynomial models fitted to the flesh firmness data collected during storage and transportation of kiwifruit along Supply Chain 3.....	116
Figure 5.33	Three non-linear models (Reciprocal, Power and Reciprocal Quadratic) fitted to the flesh firmness and core temperature data of kiwifruit collected along Supply Chain 3.....	117
Figure 5.34	Comparison of the Reciprocal and Power models fitted to the flesh firmness and core temperature data of kiwifruit collected along Supply Chain 3.....	118
Figure 5.35	Comparison of the Reciprocal and Reciprocal Quadratic models fitted to the flesh firmness and core temperature data of kiwifruit collected along Supply Chain 3.....	119
Figure 5.36	Comparison of the Power and Reciprocal Quadratic models fitted to the flesh firmness and core temperature data of kiwifruit collected along Supply Chain 3.....	120
Figure 5.37	Linear Logarithmic model fitted to the flesh firmness (kgf), Brix (%SSC) and core temperature (°C) data of kiwifruit collected along Supply Chain 2.....	122

LIST OF TABLES

TABLES		Page no.
Table 2.1	Chemical composition of ‘Hayward’ (<i>Actinidia deliciosa</i>) kiwifruit....	13
Table 5.1	Summary of flesh firmness (kgf), Brix (%SSC) and core temperature (°C) of kiwifruit belonging to the three grower lines along Supply Chain 1.....	83
Table 5.2	Summary of flesh firmness (kgf), Brix (%SSC) and core temperature (°C) of kiwifruit belonging to the three grower lines along Supply Chain 2.....	89
Table 5.3	Summary of flesh firmness (kgf), Brix (%SSC) and core temperature (°C) of kiwifruit belonging to the three grower lines along Supply Chain 3.....	95
Table 5.4	Overview of firmness loss models for Supply Chain 1.....	100
Table 5.5	Overview of storage potential models for Supply Chain 1.....	104
Table 5.6	Overview of firmness loss models for Supply Chain 2.....	109
Table 5.7	Overview of storage potential models for Supply Chain 2.....	111
Table 5.8	Overview of firmness loss models for Supply Chain 3.....	116
Table 5.9	Overview of storage potential models for Supply Chain 3.....	121

LIST OF APPENDICES

APPENDICES		Page no.
APPENDIX A:	Raw data collected along the supply chains.....	152
A1	Measurement of flesh firmness (FF), soluble solids content (SSC) and core temperature (CT) along Supply Chain 1.....	153
A2	Measurement of flesh firmness (FF), soluble solids content (SSC) and core temperature (CT) along Supply Chain 2.....	162
A3	Measurement of flesh firmness (FF), soluble solids content (SSC) and core temperature (CT) along Supply Chain 3.....	171
APPENDIX B:	Temperature data collected along the supply chains retrieved from data loggers.....	180
B1	Temperature recordings along Supply Chain 1.....	180
B2	Temperature recordings along Supply Chain 2.....	201
B3	Temperature recordings along Supply Chain 3.....	211
APPENDIX C:	Statistical Analysis.....	230
C1	Normality test results for data collected along Supply Chain 1..	230
C2	Normality test results for data collected along Supply Chain 2..	234
C3	Normality test results for data collected along Supply Chain 3..	237
C4	Paired T-test results for flesh firmness data collected along Supply Chain 1.....	241
C5	Paired T-test results for soluble solids content (Brix) data collected along Supply Chain 1.....	247
C6	Paired T-test results for flesh firmness data collected along Supply Chain 2.....	253
C7	Paired T-test results for soluble solids content (Brix) data collected along Supply Chain 2.....	259

C8	Paired T-test results for flesh firmness data collected along Supply Chain 3.....	265
C9	Paired T-test results for soluble solids content (Brix) data collected along Supply Chain 3.....	271
C10	One-way ANOVA results for Supply Chain 1.....	276
C11	One-way ANOVA results for Supply Chain 2.....	277
C12	One-way ANOVA results for Supply Chain 3.....	279
APPENDIX D:	Modelling results for the three supply chains.....	281
D1	Firmness loss models fitted to the data collected along the supply chains.....	281
D2	Storage potential models developed for data collected along the supply chains.....	287
APPENDIX E:	Packing material details.....	292
APPENDIX F:	Zespri Grade Standards.....	394

ABBREVIATIONS

AIC	=	Akaike Information Criteria
ACC	=	1 aminocyclopropane-1-carboxylic acid
ANOVA	=	Analysis Of Variance
ATO	=	Agricultural Trade Office
CA	=	Controlled atmosphere
CSIRO	=	Commonwealth Scientific and Industrial Research Organisation
CT	=	Core temperature
DD	=	Degree-days
FEFO	=	First expire, first out
FF	=	Flesh firmness
FIFO	=	First in, first out
GAP	=	Good Agricultural Practice
HDPE	=	High Density Polyethylene
IEP	=	Inverse Exponential Polynomial
MA	=	Modified atmosphere
NTC	=	Negative temperature coefficient
PET	=	Polyethyleneteraphthalate
R&D	=	Research and Development
RH	=	Relative humidity
SAM	=	s-adenosylmethionine
SE	=	Simple Exponential
SEM	=	Scanning electron microscope
SSC	=	Soluble solids content
TA	=	Titrateable acidity
WTC	=	White core inclusions