ABSTRACT

The goal of this research was to investigate changes in the physiological properties including firmness, stiffness, weight, background colour, ethylene production and respiration of 'Cripps Pink' apple stored under different temperature and atmosphere conditions,. This research also seeks to establish mathematical models for the prediction of changes in firmness and stiffness of the apple during normal atmosphere (NA) storage.

Experiments were conducted to determine the quality changes in 'Cripps Pink' apple under three sets of storage conditions. The first set of storage conditions consisted of NA storage at 0^{o}C, 2.5^{o}C, 5^{o}C, 10^{o}C, 20^{o}C and 30^{o}C. In the second set of conditions the apples were placed in NA cold storage at 0^{o}C for 61 days, followed by NA storage at the aforementioned six temperatures. The third set of conditions consisted of controlled atmosphere (CA) (2 kPa O_2 : 1 kPa CO_2) at 0^{o}C storage for 102 days followed by NA storage at the six temperatures mentioned previously.

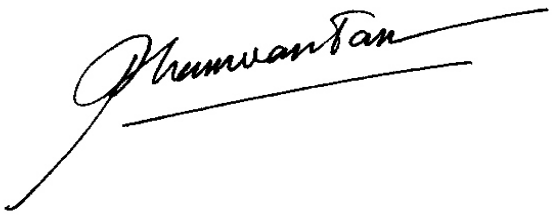
The firmness, stiffness, weight loss, skin colour, ethylene and carbon dioxide production of the apples were monitored at specific time intervals during storage. Firmness was measured using a HortPlus Quick Measure Penetrometer (HortPlus Ltd, Hawke Bat, New Zealand); stiffness was measured using a commercial acoustic firmness sensor-AFS (AWETA, Nootdorp, The Netherlands). Experimental data analysis was performed using the GraphPad Prism 4.03, 2005 software package. The Least-Squares method and iterative non-linear regression were used to model and simulate changes in firmness and stiffness in GraphPad Prism 4.03, 2005 and DataFit 8.1, 2005 softwares.

The experimental results indicated that the firmness and stiffness of 'Cripps Pink' apple stored in NA decreased with increases in temperature and time. Under NA, the softening pattern was tri-phasic for apples stored at 0^{o}C, 2.5^{o}C and 5^{o}C for firmness, and at 0^{o}C and 2.5^{o}C for stiffness. However, there were only two softening phases for apples stored at higher temperatures. NA at 0^{o}C, 2.5^{o}C and 5^{o}C improved skin background colour and extended the storage ability of apples compared to higher temperatures. CA during the first stage of storage better maintained the firmness and stiffness of the apples. However, it reduced subsequent ethylene and carbon dioxide (CO_2) production after removal from storage. Steep increases in ethylene and CO_2 production coincided with rapid softening in the fruit flesh and yellowing of the skin background colour, under NA conditions.

The exponential decay model was the best model for predicting changes in the firmness, stiffness and keeping quality of the apples. The exponential decay model satisfied the biochemical theory of softening in the apple, and had the highest fitness to the experimental data collected over the wide range of temperatures. The softening rate increased exponentially with storage temperature complying with the Arrhenius equation. Therefore a combination of the exponential decay model with the Arrhenius equation was found to best characterise the softening process and to predict changes in the firmness and stiffness of apples stored at different temperatures in NA conditions.

DECLARATION OF ORIGINALITY

The contents and subject matter of this thesis are the original work conducted by the author, except where otherwise acknowledged. This thesis contains no materials that has been submitted for the award of any other degree or diploma in any university. Some of the results of this research have been published and presented at several national and international conferences (Appendix 1).



Tan Van Pham

ACKNOWLEDGEMENTS

I wish to acknowledge the following people and institutions for their outstanding support and assistance during my candidature for the PhD degree at the University of Sydney.

Firstly, I sincerely express my deep gratitude to my supervisor, Associate Prof. Dr. Robyn McConchie for her unlimited support with continuous advice and guidance during my candidature. I gratefully acknowledge the assistance and guidance of my co-supervisors, Dr. Stephen Morris, Dr. David Tanner, and Dr. Ric Herbert who have given me valuable support during my study.

I express my sincere thanks to Vietnam Government and Vietnam Ministry of Education and Training for the PhD scholarship.

It is my great pleasure to thank Dr. Jenny Jobling from the University of Sydney, Dr. Michael Forbes Smith from the Sydney Post-harvest Laboratory, North Ryde, NSW, Australia; Dr. Anowarul Islam Bokshi from the University of Sydney, Dr. Nicholas Smale from Food Science Australia, CSIRO, North Ryde, Dr. Andrew East from Massey University, New Zealand, Penelope Symes from Sydney Post-harvest Laboratory and all the Food Science CSIRO staff for their enthusiastic technical assistance during my experiments at CSIRO in 2004 and 2005.

I would like to thank Dr. Hannah James for providing the apple firmness data sets for the model validations. I also thank Ms. Kim Yen Phan Thien from the University of

NSW for assistance with editing and all staff, friends and colleagues at the University of Sydney and the Sydney Post-harvest Laboratory who gave me cheerful support during the last four years.

Finally, I express my sincere thank to my parents, all members of my great family in Vietnam for their unlimited support. I specially thank my lovely wife, Ms. Ngoc Mai Thi Huynh, for sharing my difficulties, providing unconditional assistance and warm encouragement during my study in Australia.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREDICTION OF CHANGE IN FIRMNESS OF 'CRIPPS PINK' APPLES

PREDICTION OF CHANGE IN STIFFNESS OF 'CRIPPS PINK' APPLES

LIST OF ABBREVIATIONS

A	Frequency factor (Day $^{-1}$)
ACC	1-aminocyclopropane-1-carboxylic acid
ACC-O	ACC oxidase
ACS	ACC synthase
AFS	Acoustic firmness sensor
Ar	Argon
AVG	Aminoethoxyvinylglycine
C*	Chroma, intensity of colour
CA	Controlled atmosphere
CO_2	Carbon dioxide
C_2H_4	Ethylene
Ea	Activation energy (J.mol^{-1})
Fmin	Minimum firmness (kg.cm^{-2})
f	Resonant frequency (Hz)
h	Hue angle of colour
IEC	Internal ethylene concentration
K	Potassium
k_s	Softening rate (Day^{-1})
$k_{s'}$	Softening rate caused by weight loss (% $^{-1}$)
k_{sbc}	Softening rate caused by biochemical reactions (Day^{-1})
k_{swl}	Softening rate caused by weight loss (Day^{-1})
L*	Lightness of colour
LE	Low-ethylene
LE-CA	Low-ethylene controlled atmosphere
LO	Low-oxygen
LO-CA	Low-oxygen controlled atmosphere
MA	Modified atmosphere
MT	Magness-Taylor
m	The mass of the plunger (kg)
N_2	Nitrogen
NA	Normal atmosphere (21kPa O_2:0.04kPa CO_2:78kPa N_2:0.9kPa Ar)
NAA	Napthaleneacetamide
O_2	Oxygen
P	Phosphorus
p_a	Water vapour pressure of the air (Pa)
PAL	Phenylanune ammonia-lyase
PME	Pectin methyl esterase
p_s	Water vapour pressure at the surface of apple (Pa)
PG	Polygalacturonase
R	The universal gas constant, R = 8.314 J.mol^{-1}K^{-1}
RH	Relative humidity of air (%)
S	Stiffness index

Smin	Minimum stiffness (Stiffness Index - S)
Span	The drop in firmness (or stiffness) from the initial value to the minimum value ($kg.cm^{-2}$ or S)
S(w)	Stiffness of apple at weight loss level - *w,* (S)
T	Storage temperature (^oC or K)
t	Storage time (Day)
TSS	Total soluble solids (%)
ULO	Ultra-low oxygen
W	Weight of apple fruit (kg)
w	Weight loss of apple (%)
W_i	Weight of the apple at the beginning of storage (g)
W_t	Weight of the apple at the storage time – *t* (g)
wvpd	Water vapour pressure deficit, the difference in pressure between the fruit and the air (Pa)