Postharvest Apple Softening: Effects of At-harvest and Post-harvest Factors

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

Doctor of Philosophy in Plant Science

at

Massey University
Palmerston North
New Zealand

Jason William Johnston

2001

MASSEY UNIVERSITY

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Abstract

'Cox's Orange Pippin' (COP) and 'Royal Gala' (RG) are rapid softening apple cultivars. This makes it difficult for growers to meet minimum firmness standards in the marketplace. Research was undertaken to characterise softening curves of COP and RG in relation to different at- and post-harvest factors, and to compare these cultivars with the slower softening cultivars 'Granny Smith' (GS) and 'Pacific Rose™' (PR). Regular measurement of firmness during low-temperature storage showed that the postharvest softening curve for all cultivars was triphasic with an initial slow softening phase (I), followed by a phase of more rapid softening (II), and then a final slow softening phase (III). Phase I largely determined the fruit market life for firmness, as fruit with a short phase I had less market life than fruit with a longer first phase. Phase I of RG and COP was lengthened by harvesting fruit at an earlier rather than later maturity, by rapidly cooling fruit after harvest to 0.5-3°C, and by placing fruit in controlled atmospheres (CA). Rate of phase II softening was not affected by harvest maturity, but decreased as storage temperature was reduced from 22 to 0°C, and was reduced in CA relative to air. A modified Arrenhius equation described softening rates of COP and RG at different temperatures, where softening rate increased from 0°C to a maximum at 22°C, and then decreased through 35°C. In contrast, this equation could not describe softening rates of PR and GS at different temperatures, as both cultivars softened slowly at similar rates from 0-12°C, and phase II did not occur at 20-35°C. Prior cold or ethylene treatment induced phase II softening at 20°C for GS, but not PR. Internal ethylene concentration (IEC) may have a role in regulating onset of phase II softening in RG and COP at 0-35°C, while for GS and PR fruit sensitivity to ethylene may have a more important regulatory role than IEC. A prototype model was developed for estimating loss of RG and COP firmness through the postharvest handling chain. This model has potential to improve commercial management of the "soft fruit" problem in the marketplace.

Thesis summary

Consumers worldwide are demanding apples that are crisp and crunchy, and not dry or mealy. However, some early season cultivars soften rapidly after harvest making it difficult for growers to meet these consumer requirements. This research was undertaken to obtain information on how different pre- and postharvest factors influence softening rates of the early season apple cultivars 'Royal Gala' (RG) and 'Cox's Orange Pippin' (COP). The softening characteristics of these rapid softening cultivars were compared with the slow softening 'Granny Smith' (GS) and 'Pacific Rose' (PR) cultivars, in an attempt to determine why the RG and COP cultivars soften rapidly during postharvest handling. Factors studied in this thesis included harvest maturity, fruit size, orchard, and the temperature and atmosphere during storage.

Regardless of the factor studied, the postharvest softening curves for RG and COP cultivars was triphasic, with an initial slow softening phase immediately after harvest, followed by a phase of more rapid softening, and then a final slow softening phase. COP and RG fruit harvested at a later maturity were softer at harvest, and subsequently had a shorter initial slow softening phase during storage at 0-3^{o}C or 20^{o}C, than fruit picked less mature. Variation in postharvest softening rates of fruit from different orchards in two seasons was largely accounted for by differences in maturity at harvest, where fruit from orchards picked at an earlier maturity generally softened slower in storage than fruit from orchards picked at a later maturity. Fruit size had a minimal effect on all phases of softening when COP and RG were harvested at a early to mid stage of maturity, but at a late stage of maturity smaller fruit softened slower than both medium and large fruit.

Temperature influenced the firmness of apples both physically and physiologically. RG, COP and GS fruit were physically firmer at harvest, and physically softer after storage, when firmness was measured at a fruit temperature of 20^{o}C rather than at 0-3^{o}C. In contrast, firmness of PR was not affected by fruit temperature during measurement, regardless of prior storage duration. The physiological influence of temperature on softening rates differed between cultivars. Softening of RG and COP at different temperatures was described by a modified Arrenhius equation, where rate of softening increased as storage temperature increased from 0 to 22^{o}C, and decreased thereafter as temperature increased through 35°C. Softening of GS and PR at different temperatures could not be described by a modified Arrenhius equation, as these cultivars softened slowly and at similar rates from 0 to 12°C, and rapid phase softening did not occur at 20 to 35°C. The non-occurrence of rapid phase softening in GS and PR at 20°C was overcome by prior ethylene or cold treatment in GS, but not in PR. Apple cultivars also had different responses to prior temperature treatments, where the softening rate at a given temperature was similar regardless of prior times at 0 to 20°C for both RG and COP, but the longer that GS fruit were stored at 0.5°C the slower the subsequent softening rate was at 20°C. PR was unique in that rapid phase softening did not occur at 20°C, regardless of prior ethylene or cold treatment. It is possible that PR maybe a mutant genotype of apple with reduced capacity for ethylene biosynthesis and action, and hence softening.

Storage of RG and COP in controlled atmospheres (CA) significantly increased the initial slow softening phase and reduced the rate of rapid phase softening when compared to air storage. However for both cultivars, CA was most effective at reducing softening when applied during the initial slow softening phase. Exposure to CA had minimal effects on subsequent softening rates in air at low or shelf life temperatures.

The mechanism by which all these factors influenced softening may be mediated by ethylene, as the initial slow softening phase occurred when internal ethylene concentrations were low (<1.5 $\mu l.l^{-1}$), and the rapid softening phase occurred once IEC's increased from this low basal concentration for all experiments. Thus, it is suggested that the onset of rapid phase softening may be induced by system II ethylene production. However, exceptions to this relationship were observed for GS and PR at 20°C, as the onset of rapid phase softening in GS was delayed relative to the prior cold treatment induced increase in IEC at 20°C, and rapid phase softening was not induced in PR at 20°C despite IEC's being in excess of 100 $\mu l.l^{-1}$. Thus, the fruits sensitivity to ethylene may have a more important role in regulating rapid phase softening than the ethylene concentration *per se* in GS and PR at shelf life temperatures.

Results from temperature studies allowed development of a prototype model (FirmCalc) that describes the influence of temperature on softening of RG and COP through

different phases of postharvest handling. Once harvest maturity, orchard and CA are accounted for in this model, it should be possible to predict softening rates of RG and COP before storage, and therefore provide a tool that can be used commercially to assist with management of the "soft fruit" problem in the marketplace.

Acknowledgements

I wish to thank my supervisors, Professor Errol Hewett and Dr F. Roger Harker for their excellent supervision throughout this thesis. I also thank Professor Nigel Banks for his input during the first 1½ years of my thesis program as a supervisor, and his successor Drs Maarten Hertog for providing invaluable input on data analysis, interpretation, and the construction of this thesis. I also thank Professor Hewett for becoming an invaluable friend to my wife and myself during the last three years.

The research performed in this thesis would not have been possible without the continued support of New Zealand Pipfruit Limited (formerly ENZAFRUIT New Zealand (International)), through awarding me the Don Sinclair Research Fellowship, and providing funding and fruit for experimentation. In particular I thank Doug King, Duncan Park, Christine Bromley, Barbara Alexander, Sonja Reid and Mike Butcher.

I am also grateful for the financial support of the Claude McCarthy Fellowship, New Zealand Fruitgrowers Charitable Trust, Royal Society of New Zealand, and New Zealand Society of Plant Physiology, that allowed my participation in the 4th International Conference on Postharvest Science in Israel, March 2000. This was my first international conference, and was an invaluable experience.

I thank Peter Young, Michael Moss and David Easton for allowing orchard access and the provision of export quality fruit. I also thank Jill Stanley and her colleagues at HortResearch for picking the Nelson fruit and coordinating transport of this fruit to Palmerston North.

From Massey University I thank Chris Rawlingson and Bob Toes for assistance in analysing tissue digests for mineral concentrations, Hugh Neilson for assistance with microscopy work, Ray Johnstone and Sue Nicholson for coordinating and managing the coolstorage facilities for my experiments, Ben Anderson and Ewen Cameron of the Fruit Crops Unit for being an invaluable and flexible source of fruit for experiments, Lorraine Davis for coordinating the ordering of materials essential for my experiments, Lois Mather for taking the stress out of managing the experimental budgets, Pam Howell for assistance with report preparations, Simon Brown for assistance with NIR measurements, and Associate Professor M.H. Behboudian, Dr S. Lawes, Dr D.J. Woolley, Dr B. MacKay, Dr K. Funnell, Dr K. Fisher, Dr M. Nichols, Dr K. Maguire and Dr L. Opara for critical comments on chapters presented in this thesis.

This thesis would not have been possible without the friendship and advice (both personal and professional) of fellow students Jayson Benge and Paul Johnstone, and Horticultural Science technician Chris Rawlingson, who were worthy opponents at squash and golf. I also thank the other Horticultural Science postgraduates for their friendly banter in the various computer rooms, and during social activities.

Lastly, I thank the emotional support and inspiration that my family, and in particular my wife Sarah, provided me throughout my PhD program. I also thank my sister Tippany and my mother for giving up some of their spare time to help with measurements on days when numerous measurements were required. I also thank my wife for unselfishly helping with measurements on numerous occasions, for running my experiments while I was away in Israel, and sacrificing her own thesis time to do so.

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ACC	1-Aminocyclopropane-1-carboxylic acid
ANOVA	Analysis of variance
B	Boron
Ca	Calcium
CA	Controlled atmospheres
CO_2	Carbon dioxide
COP	Cox's Orange Pippin apple cultivar
Cu	Copper
Cs	Caesium
d	Day
DC	Delay between harvest and cooling to 0.5-3°C
DF	Degrees of freedom
DM	Dry matter
DW	Dry weight
$Ea.R^{-1}$	Activation energy • gas constant^{-1} (°K)
f_1	Firmness; fruit stored at 0-3°C and measured without delay at 0-3°C (N)
f_2	Firmness; fruit stored at 0-3°C and measured after 24 hours at 20°C (N)
f_3	Firmness; fruit stored at 0-3°C, transferred to 20°C for 24 hour, and returned to 0-3°C for 24 hour before measurement (N)
$f_{-\infty}$	Initial firmness asymptote for sigmoidal softening equation (N)
$f_{+\infty}$	Final firmness asymptote for sigmoidal softening equation (N)
f_H	Firmness at harvest (N)
Fruc.	Fructose
Δf_{temp}	Physical change in firmness with increasing temperature (N.°C^{-1})
FW	Fresh weight
g	Gram
Gluc.	Glucose
GS	Granny Smith apple cultivar
h	Hour
H1	First harvest date
H2	Second harvest date

H3	Third harvest date
H4	Fourth harvest date
H5	Fifth harvest date
HCl	Hydrochloric acid
$\Delta H.R^{-1}$	Increment of enthalpy • gas constant^{-1} (°K)
hue°	Skin greenness (hue angle)
IEC	Internal ethylene concentration ($\mu l.l^{-1}$)
IW	Temporary period of intermittent warming at 10-20°C during low temperature storage at 0-3°C
K	Potassium
k	Rate of change for sigmoidal softening equation (day^{-1})
k_a	Rate constant for modified Arrenhius equation
kg	Kilograms
l	Litre
LSD	Least significant difference
M	Molarity (mol.l-1)
MCP	1-Methylcyclopropene
Mg	Magnesium
mg	Milligram
min	Minute
ml	Millilitre
mol	Mole
mmol	Millimole
Mn	Manganese
N	Newtons
N_2	Nitrogen
Na	Sodium
NaOH	Sodium hydroxide
nmol	Nanomole
ns	Not significant, $P>0.05$
NZ	New Zealand
O_2	Oxygen
P	Probability

P	Phosphorus
PG	Polygalacturonase
PME	Pectin methyl esterase
PR	Pacific Rose™ apple cultivar
r	Correlation coefficient
R^2	Coefficient of determination
RA	Regular atmosphere (air)
r_{CO_2}	Respiration rate ($nmol.kg.s^{-1}$)
RG	Royal Gala apple cultivar
RH	Relative humidity (%)
s	Second
SPI	Starch pattern index
Sr	Strontium
$\Delta S.R^{-1}$	Increment of entropy • gas constant^{-1}
Suc.	Sucrose
t	Time (day)
T	Temperature (^oC)
TA	Titratable acidity ($mmol.l^{-1}$)
TSS	Total soluble solids (%)
Δt_{temp}	Physical change in tensile strength with increasing temperature ($N.^oC^{-1}$)
µl	Microlitre
µmol	Micromole
Zn	Zinc
*	Significant at $P \leq 0.05$
**	Significant at $P \leq 0.01$
***	Significant at $P \leq 0.001$