

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.

TEMPERATURE EFFECTS ON KIWIFRUIT MATURATION

A thesis presented in partial fulfilment of
the requirements for the degree of
Doctor of Philosophy
in
Horticultural Science
at
Massey University, Palmerston North,
New Zealand.

Nicola Gillian Seager
1993

**Massey University Library
Thesis Copyright Form**

Title of thesis:

- 1) (a) I give permission for my thesis to be made available to readers in Massey University Library under conditions determined by the Librarian.
- (b) ~~I do not wish my thesis to be made available to readers without my written consent for ... months.~~
- (2) (a) I agree that my thesis, or a copy, may be sent to another institution under conditions determined by the Librarian.
- (b) ~~I do not wish my thesis, or a copy, to be sent to another institution without my written consent for ... months.~~
- 3) (a) I agree that my thesis may be copied for Library use.
- (b) ~~I do not wish my thesis to be copied for Library use for ... months.~~

Signed Nicky Seeger

Seeger, N. G

Date 3/9/93

The copyright of this thesis belongs to the author. Readers must sign their name in the space below to show that they recognise this. They are asked to add their permanent address.

NAME AND ADDRESS

DATE

ABSTRACT

The effect of temperature on rate of kiwifruit maturation was studied using container-grown vines placed in controlled environments and field-grown vines from four orchards (Kerikeri, Te Puke, Palmerston North and Riwaka) at the geographical extremes of the kiwifruit growing regions. Soluble solids concentration (SSC) and partitioning of carbohydrate between starch and total sugar concentrations were studied at different stages of maturation in both the controlled environment and field work. Flesh firmness, dry matter concentration and fruit growth changes during fruit maturation were also measured. The effect of carbohydrate status on fruit maturation was determined by manipulating it using girdling of field-grown vines. A model relating changes in SSC to temperature was derived using data collected from controlled environment treatments. This model was applied to field-grown vines using meteorological data from kiwifruit growing regions.

Use of controlled environments quantified changes in kiwifruit during maturation. Increase in SSC and total sugar concentration, and decrease in starch concentration were faster at cooler than warmer mean temperatures, irrespective of minimum temperature *per se* or magnitude of the difference between maximum and minimum temperature. A temperature perturbation altered the partitioning of carbohydrate compared to treatments where a perturbation did not occur. In some years fruit were not responsive to any temperature treatments; these fruit had not reached the stage of development at which they were able to respond to temperature. Differences in rate of fruit maturation were found among orchard sites. Some of these differences, such as decrease in starch concentration and increase in total sugar and SSC could be attributed to the effect of temperature.

Girdling kiwifruit laterals altered carbohydrate concentration and affected rate of fruit maturation. Carbohydrate concentration was higher in fruit from the 5:1 than 1:1 leaf:fruit ratio treatment. Fruit in the 5:1 treatment matured similarly to fruit from ungirdled vines, compared to delayed maturation in fruit from the 1:1

treatment. Carbohydrate concentration in this treatment may be insufficient to support fruit maturation.

The model developed to predict the rate of change in SSC during kiwifruit maturation was made up of two components; a state-dependent physiological response function and a temperature-dependent rate function. The base + exponential model was chosen to represent the state-dependent physiological response function, based on SSC being separated into two components; basal SSC and maturation SSC. The temperature-dependent rate function from container-grown vines placed in controlled environments was successfully transported to fit SSC in field-grown vines at different orchard locations. The model was developed using continuous temperature records but was later modified to use daily maximum and minimum temperatures allowing greater practical application. The partial rate coefficient accounted for most of the physiological differences between years, orchards and experiments; it required fitting at each orchard location. Transportability of the partial rate coefficient was demonstrated between years for two orchard locations. The model, therefore, has great potential for prediction of harvest date of kiwifruit in different regions and seasons.

ACKNOWLEDGEMENTS

I would like to thank my supervisors Prof. Errol Hewett, Dr Ian Warrington and Dr Elspeth MacRae for their assistance with this study. In addition I wish to thank the two advisors to my project; Dr Paul Gandar and Dr Roger Haslemore. The modelling work in Chapter 5 was undertaken in conjunction with Dr Gandar, who wrote Appendix 5, the mathematical details that were used and interpreted in this chapter. Dr Haslemore assisted with development of the method used for starch and total sugar analyses (Appendix 1). Dr Glen Hopkirk kindly permitted use of unpublished data to test the model. I thank Drs Elspeth MacRae and Bill Snelgar for access to manuscripts in preparation. I appreciate the very practical help given by Dr Nihal de Silva with statistical advice.

I am grateful for financial support from the Department of Scientific and Industrial Research (now HortResearch) for a Biological Industries Group Fellowship, and the New Zealand Kiwifruit Marketing Board. I also appreciate the study leave made available by DSIR.

Grateful thanks to the people who have given me technical help at various critical stages during this study, and to nursery staff for tending the container-grown vines and nobly helping with the unenviable job of moving plants into the controlled environment rooms. I appreciate the assistance of HortResearch staff at Kerikeri, Te Puke and Riwaka with collection of field data in 1990, and to Mr Bill Stevens for use of his orchard at Riwaka. Thank you to Neville Gardner for the drawings in this thesis. I wish to acknowledge the support and encouragement of staff from HortResearch.

I really appreciate the interest and support of my family, especially my husband Neville, and friends during this thesis. In particular, I would like to thank members of Central Baptist Prayer Fellowship for their love and prayer support.

TABLE OF CONTENTS

Abstract	ii
Acknowledgements	iv
Table of Contents	v
List of Figures	ix
List of Tables	xiii
List of Plates	xv

1. INTRODUCTION

1.1 Kiwifruit; origins, biology and domestication	1
1.2 Fruit growth, maturation and ripening	5
1.2.1 Fruit growth	6
1.2.2 Maturation and ripening	7
Carbohydrate metabolism	7
Cell wall metabolism	10
Climacteric and ethylene	12
1.2.3 Maturity indices	15
1.3 Carbohydrates	18
1.3.1 Synthesis and degradation of starch	20
1.3.2 Effect of temperature	24
Regulatory enzymes	26
Biochemical pathways	29
Effect of warm temperatures	31
Rate of change	32
1.3.3 Respiration	33
1.4 Phenology and modelling	34
1.4.1 Controlled environment facilities	36
1.4.2 Controlled temperature experiments	38
1.4.3 Modelling	42
Types of models	42
Uses of models	43
1.5 Rationale for this study	46

2. MATURATION OF KIWIFRUIT GROWN AT DIFFERENT TEMPERATURES IN CONTROLLED ENVIRONMENTS

2.1 Introduction	48
2.2 Effect of different day and night temperatures	52
2.2.1 Materials and Methods	52
Minimum temperature treatments (Experiment 1)	55
Maximum/minimum temperature combination treatments (Experiment 2).	56
Statistical analyses	58
2.2.2 Results	62
Minimum temperature treatments (Experiment 1)	62
Maximum/minimum temperature combination treatments (Experiment 2)	65
2.3 Effect of a perturbation in temperature	72
2.3.1 Materials and methods	72
Temperature extremes and perturbation treatments (Experiment 3)	72
Temperature perturbation treatments (Experiment 4)	75
2.3.2 Results	77
Temperature extremes and perturbation treatments (Experiment 3)	77
Temperature perturbation treatments (Experiment 4)	88
Temperature perturbation treatments on immature fruit (Experiment 5)	88
2.4 Discussion	90

3. MATURATION OF KIWIFRUIT GROWN AT ORCHARDS IN FOUR CONTRASTING TEMPERATURE ENVIRONMENTS

3.1 Introduction	108
3.2 Materials and methods	111
3.2.1 Description of orchard sites	111
3.2.2 Measurements	111
3.2.3 Statistical analyses	114

3.3 Results	115
3.4 Discussion	128

4. MANIPULATION OF CARBOHYDRATE CONCENTRATIONS IN KIWIFRUIT

4.1 Introduction	137
4.2 Materials and methods	140
4.2.1 Statistical analyses	142
4.3 Results	143
4.4 Discussion	149

5. DEVELOPMENT OF A MODEL TO DESCRIBE INCREASE IN SOLUBLE SOLIDS CONCENTRATION IN KIWIFRUIT

5.1 Introduction	155
5.2 Materials and methods	159
5.3 Results and discussion	162
5.3.1 Model development	162
Empirical models	162
Improved model	166
Fitting a temperature-dependent rate function	172
5.3.2 Testing the models	180
Data from sheltered site	180
Data from orchards	184
Use of maximum and minimum temperatures	186
Studies of the daily correction factor	188
Testing of the daily correction factor at Palmerston	
North and Riwaka	191
Application of the daily correction factor to Kerikeri and	
Te Puke	194
5.4 Summary and conclusions	198

6. GENERAL DISCUSSION

6.1 Introduction	201
6.2 Differences between container-grown and field-grown vines	203
6.3 Induction of maturation	206
6.4 Carbohydrate metabolism at low temperatures	212
6.5 Description of increase in soluble solids concentration	221

7. APPENDICES

Appendix 1 Rapid estimation of fruit starch and soluble sugar concentrations in kiwifruit	225
Appendix 2 Soluble solids concentration at proximal and distal ends of fruit	234
Appendix 3 Tables of regression coefficients	240
Appendix 4 Temperature data from four orchard locations and sheltered site	244
Appendix 5 Models for accumulation of soluble solids concentration . . .	253

8. BIBLIOGRAPHY

Bibliography	272
------------------------	-----

LIST OF FIGURES

1. INTRODUCTION

Fig. 1.1 Theoretical scheme for partitioning of carbohydrate	22
Fig. 1.2 Glycolytic and gluconeogenic pathways	28

2. MATURATION OF KIWIFRUIT GROWN AT DIFFERENT TEMPERATURES IN CONTROLLED ENVIRONMENTS

Fig. 2.1 Sampling positions for physical analysis of kiwifruit	57
Fig. 2.2 Sampling positions for chemical analysis of kiwifruit	57
Fig. 2.3 Logistic curve used to fit soluble solids concentration	61
Fig. 2.4 Flesh firmness (Experiment 1)	63
Fig. 2.5 Soluble solids concentration (Experiment 1)	63
Fig. 2.6 Flesh firmness (Experiment 2)	66
Fig. 2.7 Soluble solids concentration (Experiment 2)	66
Fig. 2.8 Starch and total sugar concentrations (Experiment 2)	68
Fig. 2.9 Correlation total sugar and soluble solids concentration (Experiment 2)	70
Fig. 2.10 3D diagram starch and total sugar concentrations (Experiment 2)	71
Fig. 2.11 Flesh firmness fixed temperature treatment (Experiment 3)	78
Fig. 2.12 Flesh firmness temperature perturbation treatment (Experiment 3)	78
Fig. 2.13 Soluble solids concentration fixed temperature treatment (Experiment 3)	80
Fig. 2.14 Soluble solids concentration temperature perturbation treatment (Experiment 3)	80
Fig. 2.15 Starch and total sugar concentrations (Experiment 3)	83
Fig. 2.16 3D diagram starch and total sugar concentrations (Experiment 3)	84

Fig. 2.17 Soluble solids concentration temperature perturbation treatment (Experiment 4)	89
Fig. 2.18 Soluble solids concentration temperature perturbation treatment (Experiment 5)	89

Fig. 2.19 Rate of change in soluble solids concentration	96
--	----

3. MATURATION IN KIWIFRUIT GROWN AT ORCHARDS IN FOUR CONTRASTING TEMPERATURE ENVIRONMENTS

Fig. 3.1 Flesh firmness	117
Fig. 3.2 Soluble solids concentration	122
Fig. 3.3 Starch and total sugar concentrations	124
Fig. 3.4 Correlation total sugar and soluble solids concentration	125

4. MANIPULATION OF CARBOHYDRATE CONCENTRATIONS IN KIWIFRUIT

Fig. 4.1 Schematic diagram of kiwifruit vine showing leaf:fruit ratio treatments	141
Fig. 4.2 Flesh firmness	144
Fig. 4.3 Soluble solids concentration	146
Fig. 4.4 Starch and total sugar concentrations	147

5. DEVELOPMENT OF A MODEL TO DESCRIBE INCREASE IN SOLUBLE SOLIDS CONCENTRATION IN KIWIFRUIT

Fig. 5.1 Soluble solids concentration used in development of model	161
Fig. 5.2 Rate of change in soluble solids concentration	163
Fig. 5.3 Rate coefficients from exponential equation (Experiment 1)	165
Fig. 5.4 Rate coefficients from exponential equation (Experiment 2)	165
Fig. 5.5 Rate coefficients from exponential, base + exponential and power-law models (Experiments 1 and 2)	171
Fig. 5.6 Soluble solids concentration fitted using discrete-rates	173
Fig. 5.7 Year-independent temperature-dependent rate function	177
Fig. 5.8 Scaled temperature-dependent rate function	177

Fig. 5.9 Soluble solids concentration from 26/8C treatment fitted with exponential, base + exponential and power-law models (Experiment 2)	179
Fig. 5.10 Soluble solids concentration from 14/8C treatment fitted with exponential, base + exponential and power-law models (Experiment 2)	179
Fig. 5.11 Soluble solids concentration from sheltered site (Experiment 1) simulated with parameters from controlled environments	181
Fig. 5.12 Soluble solids concentration from sheltered site (Experiment 2) simulated with parameters from controlled environments	181
Fig. 5.13 Soluble solids concentration from sheltered site (Experiment 2) fitted with parameters from controlled environments	183
Fig. 5.14 Soluble solids concentration from Palmerston North fitted with base + exponential or power-law models	185
Fig. 5.15 Soluble solids concentration from Riwaka fitted with base + exponential or power-law models	185
Fig. 5.16 Seasonal trend of daily correction factor	189
Fig. 5.17 Trend of daily correction factor with mean temperature	190
Fig. 5.18 Soluble solids concentration from Palmerston North fitted with one, two or three parameters	192
Fig. 5.19 Soluble solids concentration from Riwaka fitted with one, two or three parameters	192
Fig. 5.20 Soluble solids concentration from Palmerston North fitted with one parameter and different values for the daily correction factor	193
Fig. 5.21 Soluble solids concentration from Riwaka fitted with one parameter and different values for the daily correction factor	193
Fig. 5.22 Soluble solids concentration from Kerikeri simulated or fitted with one parameter	195
Fig. 5.23 Soluble solids concentration from Te Puke simulated or fitted with one parameter	195
Fig. 5.24 Soluble solids concentration at four different orchards at Te Puke (1981) simulated with parameters from Te Puke (1990)	197

Fig. 5.25 Soluble solids concentration at four different orchards at Riwaka (1981) simulated with parameters from Riwaka (1990)	197
--	-----

6. GENERAL DISCUSSION

Fig. 6.1 Theoretical scheme to show effect of temperature on direction of the glycolytic pathway	217
---	-----

Fig. 6.2 Soluble solids concentration at Palmerston North simulated with parameters from Palmerston North, from end February . . .	223
---	-----

Fig. 6.3 Soluble solids concentration at Palmerston North simulated with parameters from Palmerston North, from end March	223
--	-----

LIST OF TABLES

2. MATURATION IN KIWIFRUIT GROWN AT DIFFERENT TEMPERATURES IN CONTROLLED ENVIRONMENTS

Table 2.1 Long term temperature records at four locations	54
Table 2.2 Temperatures and relative humidities (Experiment 1)	55
Table 2.3 Temperatures and relative humidities (Experiment 2)	58
Table 2.4 Coefficients from logistic curves used to fit soluble solids concentration (Experiment 1)	64
Table 2.5 Coefficients from logistic curves used to fit soluble solids concentration (Experiment 2)	67
Table 2.6 Temperatures and relative humidities (Experiment 3)	73
Table 2.7 Frequency distribution of temperature (Experiment 3)	74
Table 2.8 Temperatures and relative humidities (Experiments 4 and 5) . . .	76
Table 2.9 Dry matter at beginning and end of Experiment 3	79
Table 2.10 Coefficients from logistic curves used to fit soluble solids concentration (Experiment 3)	81
Table 2.11 Glucose, fructose, sucrose concentrations and (glucose plus fructose)/sucrose ratio (Experiment 3)	86
Table 2.12 Respiration of attached fruit (Experiment 3)	87
Table 2.13 Mean monthly temperatures at Palmerston North	98

3. MATURATION IN KIWIFRUIT GROWN AT ORCHARDS IN FOUR CONTRASTING TEMPERATURE ENVIRONMENTS

Table 3.1 Date of measuring fruit sent to Palmerston North	112
Table 3.2 Mean monthly temperatures at each orchard location	115
Table 3.3 Fruit volume at beginning and end of study	116
Table 3.4 Dry matter at beginning and end of study	118
Table 3.5 Difference in soluble solids concentration between fruit from Palmerston North measured within 2 or 24 hours of harvest . . .	119

Table 3.6 Difference in soluble solids concentration between fruit from Kerikeri, Te Puke and Riwaka measured within 2 or 24 hours of harvest	120
Table 3.7 Difference in soluble solids concentration between fruit from Palmerston North measured within 2 or 24 hours of harvest . .	121
Table 3.8 Coefficients from logistic curves used to fit soluble solids concentration	123
Table 3.9 Glucose, fructose, sucrose concentrations and (glucose plus fructose)/sucrose ratio	127

4. MANIPULATION OF CARBOHYDRATE CONCENTRATIONS IN KIWIFRUIT

Table 4.1 Fruit weight	143
Table 4.2 Dry matter	145
Table 4.3 Respiration	148

5. DEVELOPMENT OF A MODEL TO DESCRIBE INCREASE IN SOLUBLE SOLIDS CONCENTRATION IN KIWIFRUIT

Table 5.1 Fraction of time spent in each temperature class (Experiment 1)	169
Table 5.2 Fraction of time spent in each temperature class (Experiment 2)	169
Table 5.3 Fitted constants and parameters from modified Arrhenius equation for exponential, base + exponential and power-law models	176
Table 5.4 Fitted parameters from base + exponential model used to fit exponential, base + exponential and power-law models . . .	182
Table 5.5 Fitted parameters from base + exponential and power-law models for Palmerston North and Riwaka	186
Table 5.6 Regression coefficients for daily correction factor versus mean temperature	191

LIST OF PLATES

2. MATURATION IN KIWIFRUIT GROWN AT DIFFERENT TEMPERATURES IN CONTROLLED ENVIRONMENTS

Plate 2.1 Container-grown vines being maintained in the sheltered site . .	53
Plate 2.2 Container-grown vine after winter pruning	53
Plate 2.3 Nomenclature of different tissues in mature kiwifruit	59
Plate 2.4 Temperature affects vine growth (Experiment 3)	104