

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.

GROWTH AND DEVELOPMENT STUDIES WITH BROCCOLI
(Brassica oleraceae var. italica)

A thesis presented in partial
fulfilment of the requirements for the degree
of Doctor of Philosophy
in Horticulture at
Massey University

Misael T. Diputado, Jr.

April 1989

MASSEY UNIVERSITY LIBRARY



1061938447

Abstract

The influence of temperature on the growth and development of broccoli was studied in the field, the greenhouse and in controlled climate experiments at Massey University in 1985-88. In the field experiment, 6 sowings at 2-month intervals of four cultivars of broccoli were made. The effect of temperature on a number of growth and development parameters of the plant was assessed using the heat unit system. The greenhouse and controlled climate experiments were conducted as follow-up studies to determine the independent effect of temperature on the development, growth, maturity characteristics and curd quality of broccoli. In all the studies, growth analysis using the functional approach was employed.

Temperature, through the use of the heat unit system, was found to account for a major proportion of the variation between sowing dates in the rate of dry matter accumulation, rate of leaf production, times to curd initiation and maturity, and rate of curd growth. Dry matter accumulation could be expressed as a logistic function of heat unit summation (HUS) above a base temperature of 3C; rate of leaf production, a linear function of HUS above -2C; and curd growth (increase in curd diameter), as a quadratic function of HUS above 3C.

Time to curd initiation expressed as number of heat units was calculated above a base temperature of 0C. The varietal constants (total HUS from sowing to curd maturity) were calculated to be 1188, 1123, 1217 and 1347 heat units for Premium Crop, Mercedes, Idol and Fordhook Late, respectively.

The final number of leaves did not vary with sowing date but varied among the cultivars and was related to the time to curd initiation. The longer the time to curd initiation, the more leaves were formed.

The economic yield varied with sowing date and was related mainly to differences in total dry matter accumulation potential. With the cultivars, the harvest index was equally important. Differences in total dry matter accumulation between cultivars were not closely linked to differences in the relative growth rate (RGR) or any growth parameter, but were related more to

the growth duration. There was some indication of a relationship between harvest index and net assimilation rate (NAR) at curd initiation time. NAR was found to be inversely related to the specific leaf weight (SLW) which is indicative of the thickness of the leaves.

High temperature regime (30C) reduced the RGR and NAR of plants relative to a 20C regime. It did not affect rate of leaf production and did not prevent or delay curd initiation. When imposed before the curd initiation stage 1-week exposure to high temperature did not reduce curd quality. When imposed at the early or late curd development stages it reduced curd quality with the reduction being more pronounced at the latter stage. When treatment exposure was increased to two weeks similar results were obtained. Growing the plants under continuous high temperature caused a range of curd morphological abnormalities such as the presence of bracts throughout the surface of the curd, suppression of the growth of the buds or irregular elongation of curd internodes.

Acknowledgments

To Dr. Michael A. Nichols for his guidance and supervision throughout the course of the study;

To Dr. David J. Woolley and Dr. Keith J. Fisher for their constructive comments and suggestions;

To the Plant Physiology Division, DSIR for making available the climate rooms and other facilities;

To Wattie Frozen Foods for some financial assistance;

To the Visayas State College of Agriculture (ViSCA), Leyte, Philippines and the New Zealand Ministry of Foreign Relations and Trades for the scholarship grant;

To the staff and post graduate students, Dept. of Hort. Sci. and the Filipino students at Massey U. for their help during the conduct of the experiments;

To the Filipino community and all friends in New Zealand for their pleasant company;

To my parents, brothers and sisters for their great moral support;

And to my wife, Mylou for her help in computer programming and for her encouragement, patience and understanding;

MY SINCERE THANKS AND APPRECIATION.

Table of Contents

<u>Chapter</u>		<u>Page</u>
	Abstract	ii
	Acknowledgments	iv
	Table of Contents	v
	List of Figures	ix
	List of Tables	xi
	List of Plates	xiv
	List of Appendices	xv
	List of Abbreviations	xvi
	Introduction	xvii
 1	 Review of Literature	 1
1.1	Classification, General Characteristics and Use	1
1.2	Growth and Development	2
1.2.1	General Pattern of Growth and Development	2
1.2.2	Reproductive Initiation	3
1.2.2.1	Physiological and Biochemical Changes During Curd Initiation	3
1.2.2.2	Morphological Age at Curd Initiation	6
1.2.2.3	Chronological Age at Curd Initiation	7
1.2.3	Curd Morphology Development and Growth	10
1.2.3.1	Morphology of the Curd	10
1.2.3.2	Development of the Curd	11
1.2.3.3	Growth of the Curd	12
1.2.4	Use of Environmental Time Scale	13
1.2.4.1	General Concept	13
1.2.4.2	Heat Unit System	13
1.2.4.3	Selection of Appropriate Base Temperature	15
1.2.2.4	Limitations to the Use of the Heat Unit System	15

1.3	Growth Analysis	16
1.3.1	Methods of Growth Analysis	16
1.3.2	Growth Models	18
1.3.3	The Growth Parameters as Indicators of Plant Response to the Environment	20
1.4	Yield in Relation to Dry Matter Partitioning and Plant Photosynthetic and Storage Capacity	22
2	Field Experiment: The Effect of Sowing Date and Cultivar on the Growth and Development of Broccoli.	25
2.1	Introduction	25
2.2	Materials and Methods	26
2.2.1	Experimental Design and Treatments	26
2.2.2	Production of Transplants	26
2.2.3	Cultural Management Practices	27
2.2.3.1	Land Preparation and Planting	27
2.2.3.2	Fertilizer Application and Weed Control	27
2.2.3.3	Irrigation and Pest Control	27
2.2.4	Growth Analysis	27
2.2.5	The Use of the Heat Unit System	28
2.2.6	Fitting Growth Data into the Modified Richards Function against HUS	29
2.2.7	Fitting Curd Growth Data and Estimating the Time to Curd Initiation	29
2.2.8	Leaf Production	30
2.2.9	Calculating the Growth Analysis Parameters	30
2.2.10	Dry Matter Production and Partitioning	31
2.2.11	Application of a Model to Predict Curd Maturity	31
2.3	Results	32
2.3.1	Growth and Development	32
2.3.1.1	Growth and the Heat Unit System	32

2.3.1.2	Pattern of Dry Matter Accumulation	32
2.3.1.3	Growth Analysis	37
2.3.1.4	Leaf Production	49
2.3.1.5	Curd Initiation and Growth	53
2.3.1.6	A Model to Predict Curd Maturity	60
2.3.2	Total Dry Matter Production and Partitioning	60
2.3.2.1	Curd and Total Dry Matter Production	60
2.3.2.2	Dry Matter Partitioning	67
2.4	Discussion	73
2.4.1	The Heat Unit System	73
2.4.2	Plant Growth and Development	74
2.4.3	Practical Implications	79
3	Greenhouse Experiment: The Effect of Temperature and Cultivar on the Maturity Characteristics and Curd Quality of Broccoli	80
3.1	Introduction	80
3.2	Materials and Methods	81
3.2.1	Experimental Design and Treatments	81
3.2.2	Production of Seedlings	82
3.2.3	Preparation of the Medium and Pots	82
3.2.4	Transplanting and Irrigation	82
3.2.5	Imposition of the Treatments	83
3.2.6	Collection of Data	83
3.3	Results	84
3.3.1	Growth Analysis	84
3.3.2	Maturity Period	86
3.3.3	Curd Quality	86
3.3.4	Harvest Parameters	90
3.4	Discussion	90

4	Controlled Climate Experiment: The Effect of Temperature and Cultivar on the Growth, Development, Curd Quality and Maturity Characteristics of Broccoli.	96
4.1	Introduction	96
4.2	Materials and Methods	97
4.2.1	Experimental Design and Treatments	97
4.2.2	The Growth Chambers	98
4.2.3	Seedling Production and Potting	98
4.2.4	Imposition of the Treatments	98
4.2.5	Growth Analysis	98
4.2.6	Final Harvest and Data Analysis	99
4.3	Results	99
4.3.1	Growth Analysis	99
4.3.2	Leaf Production	109
4.3.3	Curd Initiation and Growth	109
4.3.4	Curd Quality and Harvest Parameters	109
4.4	Discussion	114
5	Summary	118
6	Conclusions, General Discussions and Recommendations	124
6.1	Conclusions and General Discussions	124
6.2	Recommendations	128
	Literature Cited	130
	Appendices	139

List of Figures

<u>Figure</u>		<u>Page</u>
1.1	Diagrammatic representation of the relationships between the phases of cauliflower growth, leaf production and endogenous gibberellin activity.	5
2.1	Monthly heat unit accumulation above 3C from September, 1985 to December, 1986.	34
2.2	Dry matter accumulation of broccoli (mean of 4 cultivars) at different sowing dates (assuming a constant initial RGR). Data fitted to a logistic equation.	35
2.3	Dry matter accumulation of broccoli (mean of 4 cultivars) at different sowing dates. Data fitted to a logistic equation.	36
2.4a	Trends in relative growth rate (RGR) and net assimilation rate (NAR) of broccoli with cumulative heat units (mean of 4 cultivars and 6 sowing dates). Primary data fitted to a logistic equation.	38
2.4b	Trends in leaf area ratio (LAR), specific leaf weight (SLW) and leaf weight ratio (LWR) of broccoli with cumulative heat units (mean of 4 cultivars and 6 sowing dates). Primary data fitted to a logistic equation.	39
2.5a	Relative growth rate (RGR) and net assimilation rate (NAR) of different cultivars of broccoli averaged over 6 sowing dates. Primary data fitted to a logistic equation.	40
2.5b	Leaf area ratio (LAR), specific leaf weight (SLW) and leaf weight ratio (LWR) of different cultivars of broccoli averaged over 6 sowing dates. Primary data fitted to a logistic equation.	41
2.6a	Relative growth rate (RGR) and net assimilation rate (NAR) of broccoli at different sowing dates averaged over 4 cultivars. Primary data fitted to a logistic equation.	42

2.6b	Leaf area ratio (LAR), specific leaf weight (SLW) and leaf weight ratio (LWR) of broccoli at different sowing dates averaged over 4 cultivars. Primary data fitted to a logistic equation.	43
2.7	Rate of leaf production of broccoli at different sowing dates (mean of 4 cultivars).	51
2.8	Rate of curd growth of broccoli (cultivar and sowing date means).	55
2.9	Observed and predicted number of days from sowing to curd maturity of broccoli.	63
2.10	Dry matter partitioning in broccoli (means of 4 cultivars and 6 sowing dates).	72
3.1	Diagrammatic representation of primary heads of broccoli. Top: deep head (5); shallow head (1). Bottom: wide angle branching (5); narrow angle branching (1). Source: Chowings, 1974.	85
3.2a	Time trends in relative growth rate (RGR) and net assimilation rate (NAR) of different cultivars of broccoli. Primary data fitted to a quadratic equation.	87
3.2b	Time trends in leaf area ratio (LAR), specific leaf weight (SLW), and leaf weight ratio (LWR) of different cultivars of broccoli. Primary data fitted to a quadratic equation.	88
4.1a	Time trends in relative growth rate (RGR) and net assimilation rate (NAR) of broccoli grown at 30C or 20C averaged over 3 cultivars. Primary data fitted to a quadratic equation.	100
4.1b	Time trends in leaf area ratio (LAR), specific leaf weight (SLW) and leaf weight ratio (LWR) of broccoli grown at 30C or 20C averaged over 3 cultivars. Primary data fitted to a quadratic equation.	101
4.2a	Time trends in relative growth rate (RGR) and net assimilation rate (NAR) of different cultivars of broccoli averaged over 10 temperature treatment means. Primary data fitted to a quadratic equation.	107
4.2b	Time trends in leaf area ratio (LAR), specific leaf weight (SLW) and leaf weight ratio (LWR) of different cultivars of broccoli averaged over 10 temperature treatment means. Primary data fitted to a quadratic equation.	108
4.3	Rate of leaf production of broccoli (temperature treatment and cultivar means).	110

List of Tables

<u>Table</u>	<u>Page</u>
2.1 Error mean square (EMS) about logistic function of total plant dry weight against heat unit summation at different base temperatures.	33
2.2 Relative growth rate (RGR) of broccoli at three stages of plant development (cultivar and sowing date means).	44
2.3 Net assimilation rate (NAR) of broccoli at three stages of plant development (cultivar and sowing date means).	45
2.4 Leaf area ratio (LAR) of broccoli (cultivar and sowing date means) at 3 stages of plant development.	46
2.5 Specific leaf weight (SLW) of broccoli at 3 stages of plant development (cultivar and sowing date means).	47
2.6 Leaf weight ratio (LWR) of broccoli at 3 stages of plant development (cultivar and sowing date means).	48
2.7 The coefficient of determination (r^2) as a measure of the goodness of fit of the number of leaves of broccoli cultivars against chronological or heat unit summation at different base temperatures.	50
2.8 Rate of leaf production and final number of leaves of broccoli (cultivar and sowing date means).	52
2.9 The coefficient of determination (r^2) as a measure of the goodness of fit of curd expansion of broccoli cultivars against chronological or heat unit summation at different base temperatures.	54
2.10 Variation between sowing dates in the number of days to curd initiation and heat unit summation at different base temperatures.	57
2.11 Number of days from sowing to curd initiation (CI) and curd maturity (CM) (cultivar and sowing date means).	58

2.12	Heat unit summation (HUS) at curd initiation (CI) and curd maturity (CM) (cultivar and sowing date means).	59
2.13	Estimates and standard errors of the regression coefficients derived from 2 models for the prediction of curd maturity of different cultivars of broccoli.	61
2.14	Observed and predicted number of days from sowing to curd maturity (based on 2 models) of different broccoli cultivars at different sowing dates.	62
2.15	Total plant dry weight, curd dry weight and curd diameter of broccoli (cultivar and sowing date means)	64
2.16	Total dry matter production of different cultivars of broccoli at different sowing dates.	68
2.17	Dry matter partitioning in broccoli at early seedling stage.	69
2.18	Dry matter partitioning in broccoli at curd initiation stage.	70
2.19	Dry matter partitioning in broccoli at curd maturity stage.	71
3.1	Number of days to curd maturity and curd quality of broccoli as affected by genotype and temperature treatments.	89
3.2	Temperature by stage of plant growth interaction effect on the curd quality of broccoli.	91
3.3	Cultivar by temperature interaction effect on the curd quality of broccoli.	92
3.4	Total plant weight, curd diameter, curd fresh weight and harvest index of broccoli as affected by genotype and temperature treatments.	93
4.1	Relative growth rate (RGR) of broccoli as affected by different temperature treatments (means of 3 cultivars).	102
4.2	Net assimilation rate (NAR) of broccoli as affected by different temperature treatments (means of 4 cultivars)	103

4.3	Leaf area ratio (LAR) of broccoli as affected by different temperature treatments (means of 4 cultivars).	104
4.4	Specific leaf weight of broccoli as affected by different temperature treatments (means of 4 cultivars).	105
4.5	Leaf weight ratio (LWR) of broccoli as affected by different temperature treatments (means of 4 cultivars).	106
4.6	Number of days to curd maturity and curd quality of broccoli (cultivar and temperature treatment means).	111
4.7	Total plant dry weight, curd dry weight and size, and harvest index of broccoli (cultivar and temperature treatment means).	115

List of Plates

<u>Plate</u>		<u>Page</u>
2.1	Mature curds of different broccoli cultivars sown in November 1985.	65
2.2	Mature curds of different broccoli cultivars sown in May 1985.	66
4.2a	Curds produced from plants under different temperature treatments.	112
4.2b	Curds produced from plants under different temperature treatments.	113

List of Appendices

<u>Appendix</u>	<u>Page</u>
1a Compost ingredients for the germination medium used in all experiments.	139
1b Fertilizer mix for the growing medium (Greenhouse Experiment).	139
2 Soil classification and properties.	140
3 Spray programme followed in the Field Experiment.	141
4 The error mean square (EMS) and the parameters of the logistic regression of total dry matter accumulation (common to all sowing dates and cultivars).	142
5 Heat unit summation at curd initiation time for different sowing dates calculated at different base temperatures.	143
6 Standard errors derived from the analysis of variance of the different growth parameters between different broccoli cultivars.	144
7 The climate room.	145
8 Standard errors derived from the analysis of variance of the different growth parameters as influenced by temperature regime and genotype.	146
9 A model to predict curd maturity in broccoli (Marshall and Thompson, 1987b).	147
10 Proportion of variance in reciprocal total duration from sowing to curd maturity in broccoli accounted for by temperature ($HUS; T_b=3C$) and sunshine hours.	148
11 The Modified Hoagland's Solution	149

List of Abbreviations

<u>Abbreviation</u>	<u>Meaning</u>
CI	Curd Initiation
CM	Curd Maturity
CV	Coefficient of Variation
DFS	Days from Sowing
EGA	Endogenous Gibberellin Activity
EMS	Error Mean Square
HUS	Heat Unit Summation
LAR	Leaf area ratio
LWR	Leaf weight ratio
NAR	Net Assimilation rate
RGR	Relative growth rate
SD	Sowing Date
SLW	Specific leaf weight