Effect of temperature and photoperiod on broccoli development, yield and quality in south-east Queensland

By

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DECLARATION OF ORIGINALITY

This thesis reports the original work of the author, except otherwise acknowledged. It has not been submitted previously at this or any other University.

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ABSTRACT

Broccoli is a vegetable crop of increasing importance in Australia, particularly in south-east Queensland and farmers need to maintain a regular supply of good quality broccoli to meet the expanding market. However, harvest maturity date, head yield and quality are all affected by climatic variations during the production cycle, particularly low temperature episodes. There are also interactions between genotype and climatic variability. A predictive model of ontogeny, incorporating climatic data including frost risk, would enable farmers to predict harvest maturity date and select appropriate cultivar – sowing date combinations.

The first stage of this research was to define floral initiation, which is fundamental to predicting ontogeny. Scanning electron micrographs of the apical meristem were made for the transition from the vegetative to advanced reproductive stage. During the early vegetative stage (stage 1), the apical meristem was a small, pointed shoot tip surrounded by leaf primordia. The transitional stage (stage 2) was marked by a widening and flattening to form a dome-shaped apical meristem. In the floral initiation stage (stage 3), the first-order floral primordia were observed in the axils of the developing bracts. Under field conditions, the shoot apex has an average diameter of 500 ± 3 μm at floral initiation and floral primordia can be observed under a light microscope.

Sub-zero temperatures can result in freezing injury and thereby reduce head yield and quality. In order to predict the effects of frosts, it is desirable to know the stages of development at which plants are most susceptible. Therefore, the effects of sub-zero temperatures on leaf and shoot mortality, head yield and quality were determined after exposure of plants to a range of temperatures for short periods, at different stages of development (vegetative, floral initiation and buttoning). Plants in pots and in the field were subjected to sub-zero temperature regimes from –1 °C to –19 °C. Extracellular ice formation was achieved by reducing temperatures slowly, at a rate of -2 °C per hour. The floral initiation stage was most sensitive to freezing injury, as yields were significantly reduced at –1 °C and –3 °C, and shoot apices were killed at –5 °C. There was no significant yield reduction when the inflorescence buttoning

stage was subjected to –1 °C and –3 °C. Although shoot apices at buttoning survived the –5 °C treatment, very poor quality heads of uneven bud size were produced as a result of arrested development. The lethal temperature for pot-grown broccoli was between –3 °C and –5 °C, whereas the lethal temperature for field-grown broccoli was between –7 °C and –9 °C. The difference was presumably due to variation in cold acclimation. Freezing injury can reduce broccoli head yield and quality, and retard plant growth. Crop development models based only on simple thermal time without restrictions will not predict yield or maturity if broccoli crops are frost-damaged.

Field studies were conducted to develop procedures for predicting ontogeny, yield and quality. Three cultivars, (‘Fiesta’, ‘Greenbelt’ and ‘Marathon’) were sown on eight dates from 11 March to 22 May 1997, and grown under natural and extended (16 h) photoperiods in a sub-tropical environment at Gatton College, south-east Queensland, under non-limiting conditions of water and nutrient supply. Daily climatic data, and dates of emergence, floral initiation, harvest maturity, together with yield and quality were obtained. Yield and quality responses to temperature and photoperiod were quantified. As growing season mean minimum temperatures decreased, fresh weight of tops decreased while fresh weight harvest index increased linearly. There was no definite relationship between fresh weight of tops or fresh weight harvest index and growing season minimum temperatures ≥ 10 °C. Genotype, rather than the environment, mainly determined head quality attributes. ‘Fiesta’ had the best head quality, with higher head shape and branching angle ratings than ‘Greenbelt’ or ‘Marathon’. Bud colour and cluster separation of ‘Marathon’ were only acceptable for export when growing season mean minimum temperatures were < 8 °C. Photoperiod did not influence yield or quality in any of the three cultivars. A better understanding of genotype and environmental interactions will help farmers optimise yield and quality, by matching cultivars with time of sowing.

Crop developmental responses to temperature and photoperiod were quantified from emergence to harvest maturity (Model 1), from emergence to floral initiation (Model 2), from floral initiation to harvest maturity (Model 3), and in a combination of Models 2 and 3 (Model 4). These thermal time models were based on optimised base and optimum temperatures of 0 and 20 °C, respectively. These optimised temperatures were determined using an iterative optimisation routine (simplex). Cardinal temperatures were consistent across cultivars but thermal time of phenological intervals were cultivar specific. Sensitivity to photoperiod and solar radiation was low in the three cultivars used. Thermal time models tested on independent data for five cultivars (‘Fiesta’, ‘Greenbelt’, ‘Marathon’, ‘CMS Liberty’ and ‘Triathlon’) grown as commercial crops on the Darling Downs over two years, adequately predicted floral initiation and harvest maturity.

Model 4 provided the best prediction for the chronological duration from emergence to harvest maturity. Model 1 was useful when floral initiation data were not available, and it predicted harvest maturity almost as well as Model 4 since the same base and optimum temperatures of 0 °C and 20 °C, respectively, were used for both phenological intervals. Model 1 was also generated using data from 1979-80 sowings of three cultivars (‘Premium Crop’, ‘Selection 160’ and ‘Selection 165A’). When Model 1 was tested with independent data from 1983-84, it predicted harvest maturity well. Where floral initiation data were available, predictions of harvest maturity were most precise using Model 3, since the variation, which occurred from emergence to floral initiation, was removed. Prediction of floral initiation using Model 2 can be useful for timing cultural practices, and for avoiding frost and high temperature periods.

This research has produced models to assist broccoli farmers in crop scheduling and cultivar selection in south-east Queensland. Using the models as a guide, farmers can optimise yield and quality, by matching cultivars with sowing date. By accurately predicting floral initiation, the risk of frost damage during floral initiation can be reduced by adjusting sowing dates or crop management options. The simple and robust thermal time models will improve production and marketing arrangements, which have to be made in advance. The thermal time models in this study, incorporating frost risk using conditional statements, provide a foundation for a decision support system to manage the sequence of sowings on commercial broccoli farms.

Additional Publications of Candidate Relevant to Thesis

Tan, D.K.Y., Wearing, A.H., Rickert, K.G. and Birch, C.J. (1997). A systems approach to developing a model that predicts crop ontogeny and maturity in broccoli in south-east Queensland. In 'Third Australia and New Zealand Systems Conference Proceedings: Linking People, Nature, Business and Technology.' (Eds Wollin, A.S. and Rickert, K.G.). pp. 179-187. (The University of Queensland: Gatton.)

Tan, D.K.Y., Wearing, A.H., Rickert, K.G. and Birch, C.J. (1998). Detection of floral initiation in broccoli (*Brassica oleracea* L. var. *italica* Plenck) based on electron micrograph standards of shoot apices. *Australian Journal of Experimental Agriculture* **38**(3): 313-318.

Tan, D.K.Y., Wearing, A.H., Rickert, K.G., Birch, C.J. and Joyce, D.C. (1999). Freeze-induced reduction of broccoli yield and quality. *Australian Journal of Experimental Agriculture* **39**(6) (In Press.)

Tan, D.K.Y., Wearing, A.H., Rickert, K.G. and Birch, C.J. (1999). Broccoli yield and quality can be determined by cultivar and temperature but not photoperiod in south-east Queensland. *Australian Journal of Experimental Agriculture* **39**(7) (In Press.)

Tan, D.K.Y., Birch, C.J., Wearing, A.H. and Rickert, K.G. (1999). Predicting broccoli development: I. Development is predominantly determined by temperature rather than photoperiod. *Scientia Horticulturae* (accepted.)

Tan, D.K.Y., Birch, C.J., Wearing, A.H. and Rickert, K.G. (1999). Predicting broccoli development: II. Comparison and validation of thermal time models. *Scientia Horticulturae* (accepted.)

Table of Contents

List of Tables

List of Figures

List of Plates

Abbreviations used in this Thesis

Abbreviation	Meaning of abbreviation
DWHI	Dry weight harvest index
EFI	Emergence to floral initiation
EHM	Emergence to harvest maturity
ETT	Effective thermal time
FI	Floral initiation
Fig.	Figure
FIHM	Floral initiation to harvest maturity
FSM	Floral season mean temperatures (°C)
FWHI	Fresh weight harvest index (%)
GSM	Growing season mean temperature (°C)
h	Hour
ha	Hectare
HFW	Head fresh weight (g)
HM	Harvest maturity
l.s.d.	Least significance difference
LT_{50}	Killing temperature for 50% of the population (°C)
r^2	Coefficient of determination
REC	Relative electrical conductivity
RMSD	Root mean square deviation
s.e.	Standard error
SE	Sowing to emergence
t	Metric ton
T_{base}	Base temperature (°C) for calculation of thermal time
T_{max}	Maximum temperature (°C) for calculation of thermal time
T_{opt}	Optimum temperature (°C) for calculation of thermal time
TT	Thermal time (°C d)
TTC	Triphenyl tetrazolium chloride

Terminology

Throughout this thesis, the following definitions of terms (Birch 1996) will be used.

Coefficient	Derived constant that appears in an equation. It may be a parameter.
Plant development	The change within an interval from one phenological event to another, and from one phenological interval to another in a plant.
Fitted value	The value of a dependent variable determined by substitution in a regression derived from data collected in one of the experiments reported in this thesis. Other parts of the word 'fit' are to be taken to have similar application.
Ontogeny	The sequence of events that constitute the life cycle of the plant from sowing until harvest maturity is reached (Birch 1996).
Phenology	Study of periodic biotic events that occur once in a growing season of a crop. It describes and measures developmental process, physiological processes controlling growth and development, and the environment (Alm *et al.* 1991).
Parameter	A constant for a simulation that characterises an element of a system. It is constant for a specific location or application or time period.
Prediction	The output value of a state variable provided by a model, other parts of the word 'predict' are to be taken to have similar application.

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