Modelling broccoli development, yield and quality

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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. 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. To develop procedures for predicting ontogeny, yield and quality, field studies using 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 at the University of Queensland, Gatton Campus. Cultivar, rather than the environment, mainly determined head quality attributes of head shape and branching angle. Yield and quality were not influenced by photoperiod. A better understanding of genotype and environmental interactions will help farmers optimise yield and quality, by matching cultivars with time of sowing. The estimated base and optimum temperature for broccoli development were 0?C and 20 ?C, respectively, and were consistent across cultivars, but thermal time requirements for phenological intervals were cultivar specific. Differences in thermal time requirement from floral initiation to harvest maturity between cultivars were small and of little importance, but differences in thermal time requirement from emergence to floral initiation were large. Sensitivity to photoperiod and solar radiation was low in the three cultivars used. This research has produced models to assist broccoli farmers in crop scheduling and cultivar selection in south-east Queensland.

Media summary

Predictive models of broccoli development were developed by University of Queensland researchers to assist broccoli farmers in crop scheduling and cultivar selection.

Key Words

Broccoli; Development; Yield; Quality; Temperature; Model

Introduction

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 (Tan *et al.* 1999a, b). There are also interactions between genotype and climatic variability (Tan *et al.* 1999b). 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 (Tan *et al.* 2000a, b). The objective of this study was to quantify the temperature and photoperiod response of three broccoli cultivars (Fiesta', 'Greenbelt' and 'Marathon') from emergence to floral initiation (EFI) (Tan *et al.* 1998), from floral initiation to harvest maturity (FIHM) and from emergence to harvest maturity (EHM). Yield and quality responses to temperature and photoperiod were also quantified.

Methods

Field experiment at Gatton

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 the University of Queensland, Gatton Campus (latitude 27°33’S, longitude 152°20’E, altitude 89 m) south-east Queensland, under non-limiting conditions of water and nutrient supply, using a split-split plot design. Climatic data, and dates of emergence, floral initiation, harvest maturity, together with yield and quality were obtained.

Commercial farm crops for testing the model

Crop ontogeny data to test the thermal time models for the duration from emergence to floral initiation (EFI), floral initiation to harvest maturity (FIHM) and emergence to harvest maturity (EHM) were obtained from the commercial farm located near Brookstead (latitude 27°39’S, longitude 151°21’E, altitude 364 m) on the Darling Downs. There were 60 sowings of 5 cultivars (‘Fiesta’, ‘Greenbelt’, ‘Marathon’, ‘CMS Liberty’ and ‘Triathlon’) over 2 growing seasons (1997 and 1998). Newly released cultivars, including the cytoplasmic male sterile, ‘CMS Liberty’ (Petoseed, USA) was sown 6 times, and ‘Triathlon’ (Sakata, USA) was sown 4 times in 1998.

Data collection

For each sowing date and cultivar, the daily minimum and maximum temperatures were averaged from emergence to harvest and defined as growing season mean minimum and mean maximum temperatures, respectively. The following yield measurements were made: head diameter – mean of 2 measurements taken 90? across the head (mm); and head fresh weight – gravimetric determination of head mass (g). Vegetative plant parts (bracts, leaves and stem) were cut off at the cotyledon scars and weighed separately. Fresh weight harvest index (FWHI) was defined as: FWHI = (100 ? head fresh weight) ? (head fresh weight + vegetative fresh weight). Fresh weights of tops were defined as the total plant (sum of head and vegetative) fresh weights, respectively. Head quality attribute assessments of head shape, branching angle, cluster separation, evenness of bud size, bud colour, bud size, bractiness (number of bracts protruding from head) and hollow stem were made (Tan *et al.* 1999b). Analysis of variance (ANOVA) was completed for chronological time, thermal time, and accumulated solar radiation duration of EFI, FIHM and EHM to test the independent and interactive effects of photoperiod extension, sowing date and cultivar, using the general linear model (GLM) procedure of SAS. The optimisation program, DEVEL (Holzworth and Hammer 1992), was used to determine the temperature and photoperiod responses of each cultivar from the experimental data for duration of EFI, FIHM and EHM. DEVEL contains a library of temperature and photoperiod functions which can be used separately or in combination to examine the independent and interactive effects of temperature and photoperiod. The 2-stage broken linear response best explained both the temperature and photoperiod responses.

Accumulated thermal time (?C d) (Arnold 1959) for duration of EFI, FIHM and EHM (days, i = 1 to n) were calculated using the estimated T_{base} and T_{opt} of 0 and 20 ?C (described in this study) based on the equation,

$$\text{Thermal time} = \sum^{n}_{i=1}[(T_{Dmax} + T_{Dmin})/2] - T_{base}$$

where T_{Dmax} = maximum temperature for the day, T_{Dmin} = minimum temperature for the day. All $T_{Dmin} < T_{base}$ were considered to be equal to 0 ?C, and all $T_{max} > T_{opt}$ were considered to be equal to 20 ?C (Barger System) (Arnold 1974, Tan *et al.* 2000a).

Titley’s experiments

To confirm the robustness of our EHM thermal time model, it was further tested by re-analysing data from the thesis by Titley (1985). Briefly, 3 cultivars, ‘Premium Crop’ (Arthur Yates & Co., Australia), ‘Selection 160’ and ‘Selection 165A’ (Henderson Seeds, Australia), were sown on 19 sowing dates in the University of Queensland, Gatton Campus at approximately 20 day intervals from March 1979 to March 1980 (1979-

80 sowings) using a randomised complete block design with 4 replicates. The same cultivars (11, 19 and 6 sowings of ‘Premium Crop’, ‘Selection 160’ and ‘Selection 165A’, respectively) were grown on a commercial basis for export to south-east Asia in 1983 and 1984 (1983-84 sowings). The 1979-80 sowings were used for fitting T_{base}, T_{opt} and calculating thermal time duration for EHM (Model 1) for the 3 cultivars and the 1983-84 sowings were used as independent data to validate Model 1. Since emergence and floral initiation data were not available for these sowings, emergence was assumed to be 5 days after sowing, and the EFI and FIHM thermal time models could not be tested.

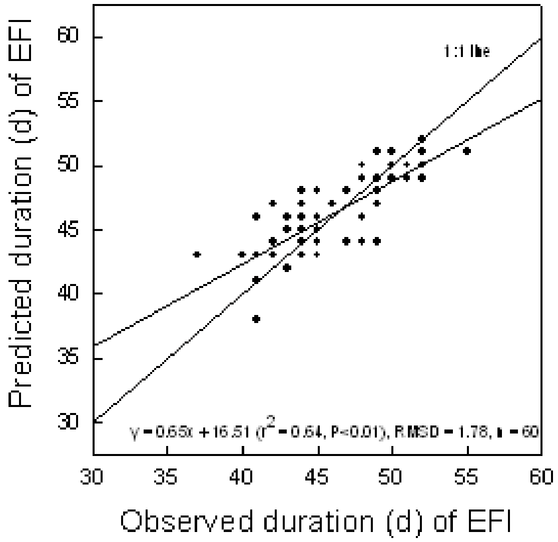
Results

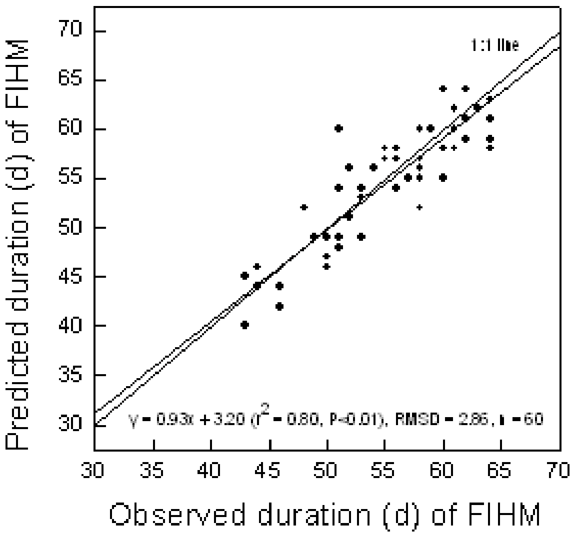
Yield and quality

In the field experiment at Gatton, 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.

Development model

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 estimated base and optimum temperatures of 0 and 20 ?C, respectively. These estimated 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 (Fig. 1a, 1b and 2a).

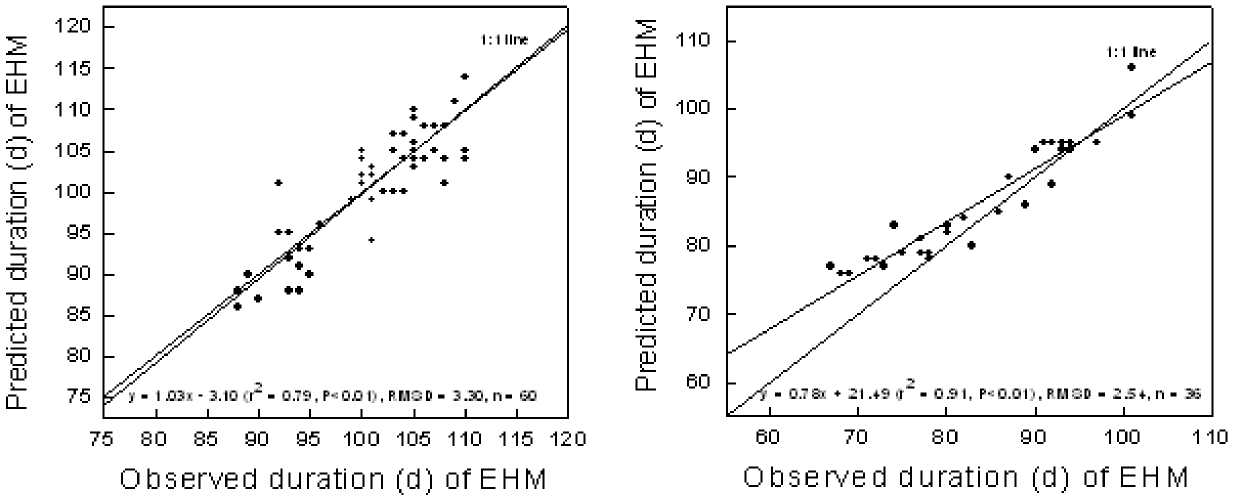




(a) (b)

Fig. 1. Comparison between predicted and observed duration (days) (a) from emergence to floral initiation (EFI) and (b) from floral initiation to harvest maturity (FIHM) for independent data from five broccoli cultivars (‘Fiesta’, ‘Greenbelt’, ‘Marathon’, ‘CMS Liberty’, and ‘Triathlon’) grown on a commercial farm in Brookstead in 1997 and 1998 (Model 2).

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 estimated 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 (Fig 2b). 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.



(a) (b)

Comparison between predicted and observed duration (days) from emergence to harvest maturity for (a) independent data from five broccoli cultivars (‘Fiesta’, ‘Greenbelt’, ‘Marathon’, ‘CMS Liberty’, and ‘Triathlon’) grown on a commercial farm in Brookstead in 1997 and 1998, and (b) for independent data from three broccoli cultivars (‘Premium Crop’, ‘Selection 160’ and ‘Selection 165A’) sown commercially during 1983-84 at Gatton College, using a single emergence to harvest maturity model (Model 4).

Conclusion

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.

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