GROWTH AND DEVELOPMENT OF HYBRID SQUASH (*Cucurbita maxima* L.) IN THE FIELD

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ABSTRACT

The growth and development of early and late sown crops of hybrid squash (*Cucurbita maxima* L.) in Pukekohe are described. Emergence appeared to depend upon the integral of temperature above 12 °C, while subsequent leaf area expansion depended upon the integral of temperature above 8 °C. The phenology of both crops was similarly described using integrals of temperature above these thresholds. Maturity dates for crops sown at various times were thus predicted for the major production areas.

Dry matter accumulation and hence yield appeared to be affected by incident radiation and temperature. The incident radiation and also dry matter accumulation were higher during most stages of phenology for the early sown crop than for the late sown crop, and this resulted in respective total fruit yields at harvest of 4.6 and 3.0 kg/m^2.

The number of female flowers increased to about 8 per plant towards crop maturity, but final fruit numbers were only 1.0 - 1.3 per plant following high rates of flower abortion. Almost all female flowers were located on the longest primary stem of each plant, which on average comprised 54% of total stem length. The implications of these results for yield potentials and efficient use of total dry matter for yield production are discussed.

Additional Key Words: Growing degree days, temperature, incident radiation, leaf area, dry matter, yield.

INTRODUCTION

Exports of hybrid squash (*Cucurbita maxima* L.) to Japan have rapidly increased from 2,500 t in 1980 to 38,000 t in 1986 (worth $35 million f.o.b.). Production has been mainly in the Pukekohe area, but has been increasing recently in other areas such as Waikato, Hawkes Bay and Canterbury.

Knowledge of the physiology of hybrid squash is limited, and the development of cultural recommendations (Wood, 1982) has been based mainly on research with similar cucurbits (e.g., pumpkins) and experience during initial seasons of hybrid squash production. Recent studies of the mineral nutrition of hybrid squash have suggested that improvements in cultural recommendations could be made by studying the growth and development of this crop (Buwalda, 1986; Buwalda and Freeman, 1986).

This paper describes a study of the growth and development of hybrid squash in the field at Pukekohe. The importance of environmental variables for growth and yield is considered and discussed in the context of sowing date and crop location. A brief analysis of flower and vine numbers in relation to final yields is also included.

MATERIALS AND METHODS

Site and Layout

Early and late sown crops of hybrid squash (cv. Delica) were grown on immediately adjacent sites at the Pukekohe Horticultural Research Station. These crops were part of a detailed study of the P nutrition of hybrid squash, to be reported elsewhere. The sowing dates were 4 October 1985 (SD1) and 6 December 1985 (SD2). The plant density was 2/m^2. Plots measured 10.5 m x 7 m, and comprised seven rows spaced at 1.5 m and 21 plants spaced at 0.33 m in each row. Each plot had two outer guard rows and a central guard row, and two sampling strips comprising two rows each. The crops were irrigated when soil moisture tensions exceeded 0.3 bar.

Measurements

Crop emergence in the field was recorded at two-day (SD1) or one-day (SD2) intervals. Germination of seeds (cotyledons fully open) on moist filter paper in an oven at constant temperature (26 °C) was recorded twice daily.

The measurements of crop growth and yield reported here were all made for plots where P was not limiting ($NaHCO_3$ soluble P, 150 mg/kg), and from four replicate plots for each sowing date. Samples of four plants (two plants from each of two adjacent datum rows) were taken at 7 day and 6 day intervals from emergence (75% of plants emerged) for SD1 and SD2 respectively. Alternate samples were taken sequentially from each side of the central guard row of each plot. Only the two completely guarded plants sampled on each occasion were retained. Leaf area, dry weight of above ground plant parts, vine length, and number and location of female flowers (or fruit) were recorded for each sample. The crops were harvested when mature. Total number of fruit and total fruit yield were recorded.

Throughout growth, incident radiation, air (1 m above ground) and soil (0.1 m depth) temperatures were recorded at 20 second intervals, at a meteorological recording facility within 200 m of the crops. Integrated heat sums (growing degree days, GDD) for each day were calculated above various base temperatures, using the sum of eight contributions of a cosinusoidal variation between observed maximum (Tmax) and minimum (Tmin) temperatures:

$$GDD_a = 1/8 \sum_{r=1}^{r=8} [T_H - a] \text{ °C days,} \qquad (1)$$

where $$T_H = Tmin + fr\,(Tmax - Tmin) \text{ °C,} \qquad (2)$$

and $$fr = \tfrac{1}{2}\,[1 + \mathrm{CO}\frac{90}{8}(2r-1)]. \qquad (3)$$

a is the assumed base temperature for growth, and a, T_H, Tmax and Tmin are in °C; negative contributions were treated as zero (Gallagher and Biscoe, 1979). There was no consideration given to optimum or maximum temperatures.

RESULTS

Environmental Parameters

The mean daily temperatures on average increased from October to January, and were always higher in the soil than in the air (Table 1). The season at Pukekohe was colder than average for October and November, but warmer than average in December and January. Mean daily incident radiation increased from October to November, but then remained relatively constant until February (Table 1).

TABLE 1: Mean daily temperatures and incident radiation levels during crop growth.

	Mean Daily Temperature (°C)		Incident radiation
	Air	Soil	(MJ/m^2/day)
October	12.4	14.0	17
November	13.7	16.1	21
December	17.0	19.5	21
January	19.1	21.6	20
February	17.8	21.3	20

Emergence

The progress of emergence for the two field crops and for seeds germinated in the oven is shown in Fig. 1. On the basis of days from sowing, emergence was most rapid in the oven (at 26 °C) followed by SD2 and then SD1. The final levels of emergence differed little, ranging from 88% for SD1 to 94% for the oven.

The importance of temperature for emergence was investigated by using GDD as a time base rather than calendar days. The base temperature for germination of hybrid squash was not known, so emergence was plotted against GDD assuming various base temperatures. The progress of emergence for the oven, SD1 and SD2 was very similar where a base temperature of 12 °C (GDD_{12}) was assumed (Fig. 1b). Base temperatures less than 12 °C suggested that the rate of emergence increased in the order SD1 > SD2 > oven, while base temperatures greater than 12 °C suggested that the rate of emergence increased in the reverse order.

Leaf Area Expansion

The expansion of the leaf area (expressed as a 'leaf area index' — leaf area per unit area of land) with days from emergence is shown on a logarithmic scale in Fig. 2a. The rate of expansion was initially more rapid for SD2 than for SD1, although the final leaf area indices were similar for the two crops (4.5 - 4.8). Leaf area expansion did not differ significantly for SD1 and SD2 where it was plotted against GDD with a base temperature for growth of 8 °C (Fig. 2b, Table 2).

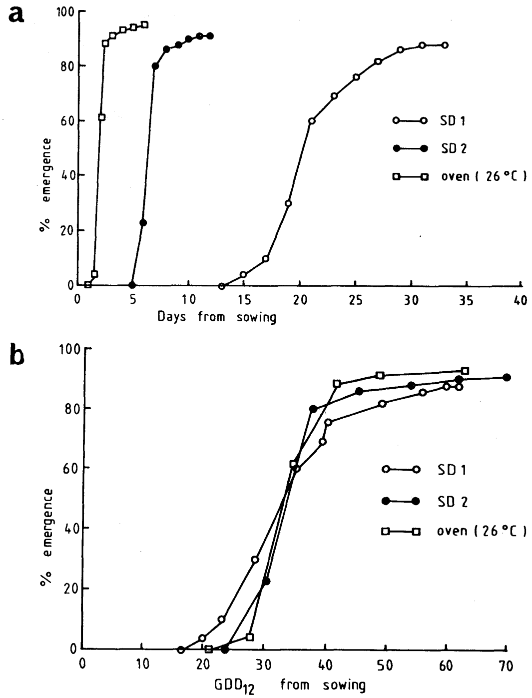

Figure 1: Progress of emergence of hybrid squash sown in the field on 4 October (O) and 6 December (●) or in the oven at 26 °C (□), plotted against (a) calendar days and (b) growing degree days above a base temperature of 12 °C (GDD_{12}).

Dry Matter Accumulation

The accumulation of above-ground dry matter for SD1 and SD2, plotted against GDD_8, is shown in Fig. 3a. Quadratic regressions (using GDD as a time base) fitted separately for SD1 and SD2 suggested a significantly higher initial rate of growth for SD1, but that subsequently the relative growth rates of the two crops were similar (Table 2). Hence the absolute dryweights for SD1 exceeded those of SD2 throughout, by up to 36% at 575 GDD_8 (Figure 3a).

The differing initial growth rates of SD1 and SD2 coincided with different incident radiation levels experienced during early growth stages. For example, SD1 experienced a total of 172 MJ/m^2 incident radiation during the first 40 GDD_8 from emergence, while SD2 experienced only 88 MJ/m^2 during the same period. Plotting dry matter accumulation against incident radiation suggested that the

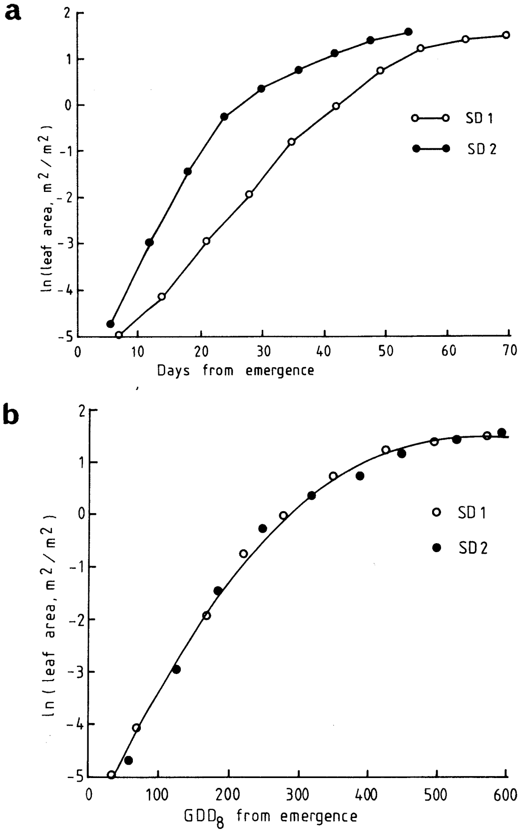

Figure 2: Leaf expansion of hybrid squash sown on 4 October (O) and 6 December (●) plotted against (a) calendar days and (b) growing degree days above a base temperature of 8°C (GDD_8) with the fitted quadratic regression (——) for SD1 and SD2.

TABLE 2: Co-efficients of quadratic regressions of leaf area and dry weight increases against growing degree days (GDD_8).

Unit of Growth	Crop	Regression Co-efficient		
		Constant	Linear	Quadratic
Leaf area (m^2/m^2/GDD)	SD1, SD2	-6.06	2.91×10^{-2}	-2.80×10^{-5}
Dry weight	SD1	-1.87	2.85×10^{-2}	-2.37×10^{-5}
(g/m^2/GDD)	SD2	-2.05	2.85×10^{-2}	-2.37×10^{-5}

growth of SD2 was more rapid than that of SD1 (Fig. 3b), demonstrating the importance of other factors (i.e., temperature) beyond the early growth stages.

Female Flower Development

The appearance of the first female flowers was at

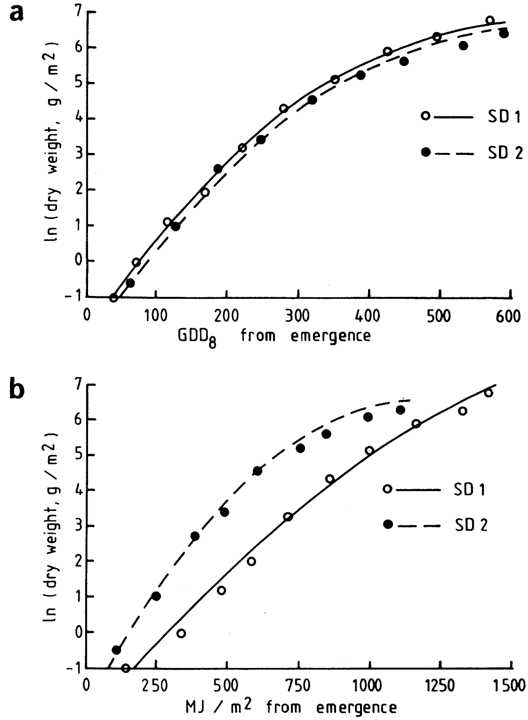

Figure 3: Dry matter accumulation of hybrid squash sown on 4 October (O) and 6 December (●) plotted against (a) growing degree days above a base temperature of 8°C (GDD_8) throughout with fitted quadratic regressions for SD1 (——) and SD2 (----), and (b) incident radiation (MJ/m^2) with fitted quadratic regressions for SD1 (——) and SD2 (----).

about 320 GDD_8 for both SD1 and SD2 (Fig. 4, with data for SD2 only). The number of female flowers then increased similarly for both crops to 7-8 per plant by the final sample. However, only 1-2 flowers per plant were successfully pollinated without subsequently aborting.

The total number of female flowers per plant was similar to the total number of primary stems (which increased from 3 to 7 per plant during the period covered in Fig. 4). Almost all the female flowers were on the longest primary stem of each plant (mean length, 4.75 m) with only 8% of all female flowers occurring on the remaining six primary stems (mean length, 0.68 m).

Yield

The development of the crop to fruit maturity was more rapid for SD2 than SD1 when expressed on the basis of calendar days, but very similar for the two crops when expressed on the basis of GDD_8 (Table 3). The total incident radiation, however, was much greater for SD1 and SD2, both from emergence to harvest (by 25%) and from when the leaf area index was 0.5 to harvest (by 20%).

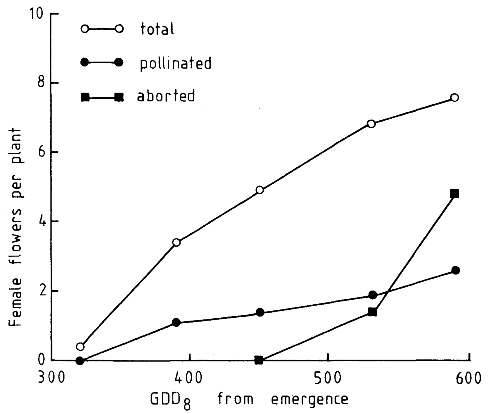

Figure 4: Numbers of female flowers of hybrid squash sown on 6 December; O, total; ●, pollinated; ■, aborted.

TABLE 3: Time to harvest, total incident radiation, and parameters of yield for hybrid squash sown on 4 October (SD1) and 6 December (SD2).

	SD1	SD2
Time to harvest		
Days from emergence	83	66
GDD_8 from emergence	730	721
Incident radiation		
MJ/m^2 from emergence	1736	1394
MJ/m^2 from LAI=0.5	1017	846
Fruit yield		
kg/m^2	4.6	3.0
Fruit/plant	1.3	1.0
Mean fruit weight (kg)	1.8	1.5

The total fruit yield at harvest was 53% greater for SD1 than SD2 (Table 3). This resulted from a 30% increase in the fruit number per plant and a 20% increase in the mean fruit weight.

DISCUSSION

The dry matter production of many C_3 crops depends greatly on leaf area and hence absorption of incident radiation (Gallagher and Biscoe, 1978). The results of this study, suggesting that temperature exerts considerable control over crop emergence and leaf area expansion of hybrid squash, are consistent with those for other C_3 crops such as lettuce (Bierhuizen *et al.*, 1973), barley (Gallagher and Biscoe, 1979), wheat (Gallagher *et al.*, 1979) and sugarbeet (Milford *et al.*, 1985).

The method used here for determining the threshold temperature for growth has been used successfully with relatively small data sets for various crops (Gallagher and Biscoe, 1979; Hay and Tunnicliffe-Wilson, 1982). The threshold temperatures thus estimated for growth of hybrid squash are similar to those reported for other species of Cucurbitaceae (Slack and Hand, 1983). It is interesting to note that the threshold temperature for emergence of hybrid squash was higher than that for subsequent growth. Different threshold temperatures for various stages of growth have been recognised for other crops (Weir *et al.*, 1984).

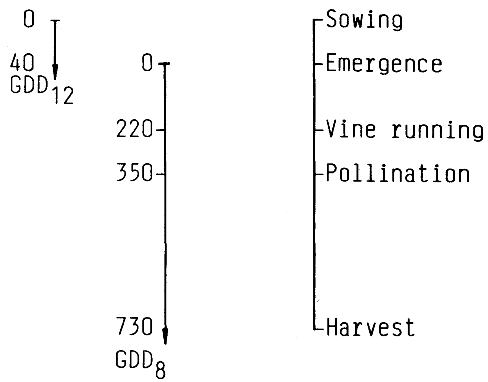

Figure 5: Summary of phenological development of hybrid squash.

TABLE 4: Estimated times to emergence and harvest for hybrid squash sown in various production areas, using the summary of crop phenology in Fig. 5 and mean meteorological data for 1981-84.

Site	Sow Date	Emergence	Harvest
Kerikeri	1 October	19 October	12 January
	1 November	9 November	25 January
	1 December	7 December	15 February
	1 January	6 January	13 March
Pukekohe	1 October	23 October	20 January
	1 November	11 November	2 February
	1 December	8 December	22 February
	1 January	7January	20 March
Rukuhia	1 October	2 November	25 January
	1 November	11 November	2 February
	1 December	8 December	21 February
	1 January	7 January	19 March
Havelock North	1 November	10 November	26 January
	1 December	7 December	22 February
	1 January	7 January	27 March
Lincoln	1 November	19 November	22 February
	1 December	11 December	13 March
	1 January	9 January	17 April

Phenological development of hybrid squash was closely related to GDD_8. For both crops, commencement of vine growth, pollination and crop maturity occurred after very similar integrals of temperature. The phenology of hybrid squash may, therefore, be described as in Fig. 5. From this summary it is possible to estimate times to emergence and harvest for crops sown in various production areas of New Zealand (Table 4). The rate of phenological development, on the basis of calendar days, generally decreases in the order Kerikeri <Pukekohe <Rukuhia <Havelock North <Lincoln.

The results here suggest that the influences of GDD and incident radiation on dry matter accumulation are inter-related (Fig. 3), and highlight the importance of the changing balance of temperature and incident radiation during the growing season. Incident radiation alone proved a poor basis for the description of dry matter accumulation (Fig. 3b) as a leaf canopy must be present to intercept radiation, and the expansion of this is dependent upon temperature. The incident radiation levels during any integral of temperature were generally higher for SD1 than SD2, reflecting the displacement between mean daily temperatures (highest in Janary) and daily incident radiation levels (similar from November to February). The resulting increase in incident radiation experienced by SD1 compared to SD2 may explain, at least partly, the higher dry matter production and yield of the early sown crop. Biscoe and Gallagher (1977) claim also that dry matter production during later stages of growth is inherently less efficient as the temperature increases, because of the temperature dependence of maintenance respiration (McCree, 1974). The changing balance of temperature and radiation during the season lead to the conclusion that yields of hybrid squash should increase as the sowing date is advanced. The limit to early sowing is essentially cold temperature which, in combination with wet soils, can damage germinating seeds and recently emerged plants. The export market for hybrid squash requires steady production from mid January to early April. This requires crops to be planted regularly over a two to three month period from early October. The lower yields of crops sown in November and December will probably restrict late planting to more southern areas and to situations where it is compatible with crop rotations.

The final yields of only 1.0-1.3 fruit per plant where almost 8 female flowers per plant were previously recorded suggests some internal control over final fruit set. In almost all cases, all female flowers occurred on the longest primary stem of each plant. This vine constituted on average 54% of total vine length per plant. The function of the minor stems, and their contribution to final yield, is not known. In Japan, hybrid squash plants are pruned to control the vegetative growth and achieve a balance between leaf area and fruit yield (Kurata and Mizuno, 1982). Broadacre production of hybrid squash would probably not accommodate such practices, but chemical manipulation of growth may be used to improve the balance between total plant dry matter and fruit yield.

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