

Phenology, leaf and yield production patterns of sweet pepper under irrigated seasonal dry lowlands conditions, Papua New Guinea

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Abstract

Under seasonal irrigated dry-lowland conditions in Papua New Guinea (PNG), phenological parameters of three sweet pepper cultivars were quantified using thermal time after transplanting ($^{\circ}\text{CdAT}$). First flowers appeared at 500-600 $^{\circ}\text{CdAT}$, while green fruit maturity for harvest averaged 1200 $^{\circ}\text{CdAT}$. Increase in leaf numbers and crop height were initially slow before increasing linearly from 400-800 $^{\circ}\text{CdAT}$, after which leaf production and plant height rates declined at 800-900 $^{\circ}\text{CdAT}$. Reduction of leaf production and plant height was attributable to assimilate distribution in favour high fruit production over vegetative structures and flower production. Fresh weight of marketable fruits was similar across cultivars; nevertheless, New Ace produced 87% of marketable fruit yield (but lower total yield) than Giant Bell and Wonder Bell, which had 74% and 80%, respectively. This study is complemented by investigating internal competition for photosynthate in sweet pepper to improve crop management practices for enhanced fruit retention and yield quality.

Keywords: Biological growth pattern, Crop phenology, *Capsicum annum*, Thermal time

Introduction

Sweet pepper (*Capsicum annum* L.) is an important vegetable crop in Papua New Guinea (PNG), with substantial market demand in urban centres and peri-urban areas. However, current production volumes of the crop are inadequate to meet the high and growing demand (Birch et al., 2011).

Sound vegetable crop management relies on an understanding of crop phenology in response to temperature and time. The mechanism of underlying variation in plant phenology within similar habitats remains nebulous (Elzinga et al. 2007). Modelling the influences of the local environment on crop phenology and yield could help with crop scheduling, reducing yield losses. For such a model to be developed it is crucial that crop phenology, allometry and the impact on yield be understood and quantified, and in many other models these parameters are related to thermal time ($^{\circ}\text{Cd}$). No such model exists for sweet pepper, and certainly no detailed work has been conducted in PNG to quantify crop responses under local conditions.

This study quantified for three sweet pepper cultivars, leaf number, plant height, and flower and fruit numbers in relation to thermal time after transplanting under irrigated dry-lowland field conditions in PNG. The relationships between thermal time and phenological development were described using fitted equations.

Materials and Methods

Field experimentation was conducted at Pacific Adventist University (PAU) farm (S 09°24.309', E 147 ° 16.343'', 50m ASL) in June -October, 2013. Three sweet pepper cultivars (Giant Bell, New Ace and Wonder Bell) were selected and grown in experimental plots (3.6 m x 3.0 m) using a randomized complete block design (RCBD). Planting density was (0.4 m x 0.75 m) between and within rows with seedlings transplanted at 5 true leaves. The soil type was described by (Doyle, Birch, Sparrow, & Oromu, 2012). Two days prior transplanting, urea (46%N) was incorporated into the soil at half (275 kg/ha) of total application rate (550 kg/ha) along with triple superphosphate (19.2% P) at 450 kg/ha. At transplanting, a further application of NPK (18%N: 4.6%P: 0%K) was applied at 250 kg/ha as a top dressing. The remaining 50% of urea was equally applied at 25 and 45 days after transplanting (DAT).

The change leaf and branch numbers were recorded from tagged plants (n=5) within two inner rows of each plot at 4-6 days interval from emergence until maturity. Other measurements included plant height; number of green and senesced (>50% of leaf area dead) leaves; the number of primary and secondary branches and internodes; the time of appearance and numbers of the first flower buds, flowers (petals fully open), fruit (>15 mm in length) and fruit maturity; and time to harvest maturity were undertaken. All measures were then related to thermal time after transplanting. Yield data was reported as green maturity while red maturity was determined from fruits on replicate plants. Data was collected every 4-6 days until fruit maturity.

All data analysis was performed using Statistix (Ver. 8.0) and R (Ver 3.2.1).

Results and Discussions

Crop phenology and thermal time

Overall observations revealed that there were differences in the duration of the phenological stages among the cultivars, with Giant Bell reaching defined phenological events later than New Ace and Wonder Bell (Table 1). These differences are important when selecting cultivars to manage environmental risks, for example, high temperatures during the onset of flowering and fruiting, and/or suitability for prolonged dry seasons. While the extended flowering period due to the indeterminate nature of sweet pepper provides an inherent plasticity, allowing plants to recover from flower loss, the availability of cultivars with differing patterns of phenological events provides additional capacity to manage environmental risks and address market needs and preferences. These considerations are important to modelling of sweet pepper development, and will require a means of quantifying phenotypic differences among genotypes. The use of a genetic 'constant' for phenological intervals e.g. transplant to first flowers, first flower to peak flowering, peak flowering to first green mature fruit may prove worthwhile.

Table 1. Mean thermal time after transplanting (°CdAT) for specific phenological stages of the three cultivars grown under hot humid conditions at the Pacific Adventist University farm, Papua New Guinea from June to November, 2013.

Cultivars	The phenological stages and duration in relation to thermal time after transplanting (°CdAT)						
	Flower Initiation	Early flowers	Early Fruits	Late flowers	Late fruits	Green fruit maturity	Red fruit maturity
Giant Bell	623a	645a	741a	1122a	1200a	1218a	1339a
New Ace	272c	529c	565c	842c	1009c	1195b	1220c
Wonder Bell	433b	584b	639b	970b	1058b	1146ab	1303b
LSD(P=0.05)	60.08	49.99	30.84	53.99	75.34	54.69	9.22

Means values of thermal times followed by same letter within each phenological parameter did not differ based on Fishers Protected LSD.

Pattern of leaf and plant height and their relationship

From our observations, it is evident that there are differences among cultivars in plant height and number of leaves (Table 2). While it is not possible to attribute this to any specific process, the findings are consistent with those of Sun and Frelich (2011), though data here (Table 2b) do not contain the range of plant heights reported in that study (25-150cm). Leaf number and plant height for all cultivars were explained using a logistic regression model ($r^2=0.95$) (Table 3). Crop height and the rates of leaf production declined after 1000-1100 °CdAT, presumably as assimilates distribution then favoured the production of fruits over vegetative structures and flower production. As this analysis has not previously been done in sweet pepper, further work to test this hypothesis is needed. From a commercial production viewpoint, it is vitally important to have plants that efficiently convert incident light into marketable product, and the ideal plant type is unlikely to be at the extremes mentioned by Sun and Frelich (2011). The work reported here used a much higher plant population (33, 333 plant per ha) than is currently used in PNG, but this population is unlikely to affect phenological development.

Table 2. The coefficients for logistic function relationship of growth parameters (leaf number and crop height) as function of thermal time. The estimates for fits were derived using logistic function, $f(x) = \frac{a}{1 + \exp(-b(Mt))}$, where, a = the maximum curve of organs, and b = the steepness of the curve, Mt = growth rates, M = constant parameters, t = thermal time after transplanting.

Growth Parameters	Cultivars	Coefficients of parameters as a function of thermal time after transplanting			Regression coef R-adjusted
		$a \pm s.e$	$b \pm s.e$	$M^*t \pm s.e$	
a) Leaf number	Giant Bell	136.9±3.6	-4.1±0.62	0.006±0.0004	0.93
	New Ace	133.0±3.2	-4.0±0.30	0.006±0.0004	0.95
	Wonder Bell	169.0±2.6	-3.1±0.23	0.006±0.0003	0.94
b) Crop height	Giant Bell	54.8±1.1	-3.1±0.11	0.004±0.0002	0.96
	New Ace	48.0±0.5	-2.4±0.04	0.004±0.0008	0.98
	Wonder Bell	56.1±0.8	-3.1±0.11	0.005±0.0002	0.96

Means values of observed and estimated were significant based on Fishers Protected LSD ($P=0.05$).

Table 3. Coefficients for linear model relationship between plant height and leaf number production as a function of thermal time for three sweet pepper cultivars from vegetative stage to reproductive organ production and harvest period.

Cultivars	Coefficient of determinants using linear model function				Regression coef R-adjusted
	$a(\text{intercept})$	$s.e$	$^+b(\text{NOLF})$	$s.e$	
Giant Bell	6.2811	0.7620	0.2869	0.0072	0.9919
New Ace	5.2921	0.9260	0.3354	0.0111	0.9859
Wonder Bell	5.9109	0.9502	0.2850	0.0108	0.9815
Cross cultivar	6.0281	0.6779	0.2979	0.0072	0.9772

***Means coefficients were significant based on Fishers Protected LSD ($P=0.05$); $^+ \text{NOLF}$ is the linear rate coefficients of leaf number related to crop height extension.**

Reproductive organ production and yield

The number of reproductive organs (flowers) produced followed a typical Bell-shaped curve while there was close to a nonlinear or sigmoid pattern for fruit number with the increasing °CdAT (Figure 1). New Ace produced a greater number of flowers earlier than the other cultivars. Later, after about 800°CdAT, Wonder Bell and Giant Bell produced a higher number of flowers than New Ace. This observation may be attributed to traits related to an increase in the number of sink organs (e.g. fruit), and changing source-sink ratios in the plants with increasing thermal time from transplanting (Heuvelink & Marcelis, 1996; Sun & Frelich, 2011).

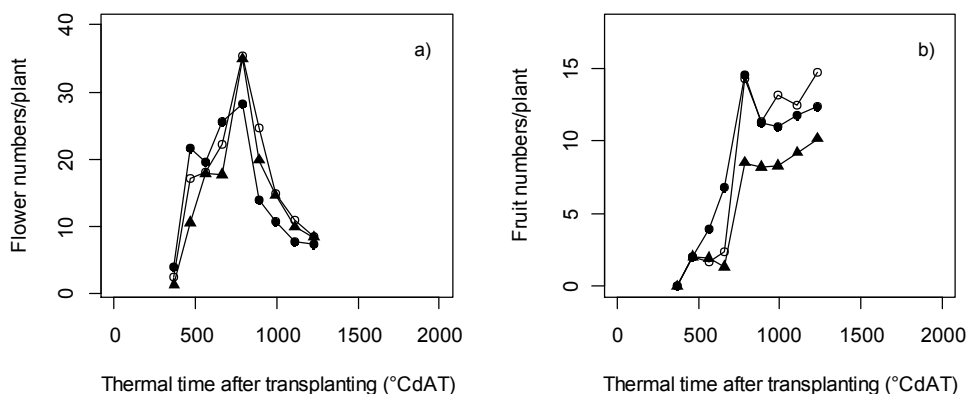


Figure 1. The progressive mean of flower (a) and fruit numbers (b) of three cultivars during sampling period. Each sampling dates are represented by symbols in three sweet pepper cultivars, New Ace (●), Giant Bell (▲), Wonder Bell (○) with number of flowers and fruits counted per sampling date, from the time of initiation of flowering to first flowering through to fruit maturity under seasonal irrigated dry-lowland conditions (range temperature of 30-35°C/18-21°C).

Marketable fruit yield was greater for New Ace, although this cultivar had lower total and net yields (Table 4). This discrepancy is explained by New Ace having larger individual fruit size. Giant Bell had the lowest number of marketable fruits and the lowest fruit number, and it is suspected that Giant Bell did not respond well to the high temperatures and prolong dry season, something observed earlier by (Marcelis, Heuvelink, Hofman-Eijer, Bakker, & Xue, 2004).

Table 4 Means of marketable and unmarketable fruit weight (grams/plant) and fruit numbers (fruits/plant) (n=5).

Cultivars	Fruit weight (g/plant)			Number of fruits (fruits/plant)			Percent of marketable and no marketable (%)	
	Total fruit weight (g/plant)	Marketable fruit weight (g/plant)	Unmarketable fruit weight (g/plant)	Total fruit numbers	Marketable fruit numbers	Unmarketable fruit numbers	Marketable fruits %	Unmarketable fruits
Giant Bell	773a	578a	194a	9b	6b	3a	74b	26a
New Ace	667b	576a	91b	13a	10a	2a	87a	14b
Wonder Bell	871a	674a	197a	15a	11a	4a	80b	23a
LSD(P=0.05)	104.76	117.80	74.81	2.74	1.38	1.76	9.48	9.48

Mean values of fruit weights and numbers followed by same letter within each yield parameters did not differ based on Fishers Protected LSD.

This study has provided baseline information on phenology, development rate and timing for green maturity and red fruit maturity of three cultivars of sweet pepper grown in dry lowland conditions of PNG. The differences in crop phenology were thought related to genotype and /or multiple abiotic and biotic factors, and further studies are required to resolve the relative importance of these factors. The vegetative organ production and increase in plant height followed a sigmoid pattern, following a well-established pattern. However, flower and fruit production showed a different temporal pattern, being a typical 'Bell Shape'. Variation among yield was an indication of edaphic limitation or the effect of biotic or abiotic factors. However, fruit retention was evident and may be attributable to assimilate supply being limited by high temperatures, this possibly exacerbated by irrigation practices, and nutritional issues especially those (e.g. low phosphorus supply) reported by (Doyle et al., 2012).

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