Flowering and fruit set in lychee (*Litchi chinensis* Sonn.) in subtropical Queensland

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Summary. The pattern of panicle and flower development of lychee (*Litchi chinensis* Sonn.) trees was studied in subtropical Queensland (lat. 27°S.). The cultivars studied were Tai So at 3 sites, Bengal at 4 sites, Kwai May Pink at 2 sites, Salathiel at 3 sites, and Wai Chee at 2 sites.

Tai So was the earliest cultivar, with panicle emergence in late May and flower anthesis in mid September. The other cultivars were 5–7 weeks later. Tai So had a longer period of flower anthesis than the other cultivars (4 weeks *v.* 1–3 weeks). Cultivars Tai So and Bengal generally had longer panicles than cvv. Kwai May Pink, Salathiel and Wai Chee (17–32 *v.* 10–14 cm), and more flowers per panicle (1800–3400 *v.* 400–900). Similarly, the number of fruit per panicle ranged from 7–33/panicle 2–3 weeks after the end of flowering, to 4–22/panicle at harvest. The proportion of female flowers setting fruit ranged from 2.1 to 19.5%. Similar estimates for fruit carried to harvest ranged from 0.8 to 6.8%.

Variations in the times of panicle emergence, panicle development, and anthesis among the cultivars in relation to seasonal progressions in temperature affected the number of fruit set. The number of fruit set per panicle increased as the number of female flowers per panicle increased. Higher numbers of female flowers were associated with maximum temperatures during flower development of 18°C, with lower numbers at 23°C. Higher maximum temperatures during anthesis (30°C *v.* 24°C) increased the proportion of female flowers setting fruit.

Introduction

The lychee (*Litchi chinensis* Sonn.) from southern China was introduced to other tropical and subtropical areas from the end of the 17th century and is now found at latitudes 15–35° in many countries (Menzel and Simpson 1990). It is a major concern of lychee growers in many locations that yields are often irregular and frequently below the trees bearing capacity (Menzel 1983, 1984). For instance, average yields of lychee orchards in southern China are usually less than 3 t/ha, although some older, well-grown orchards may produce 10–45 t/ha (Winks *et al.* 1983). Bearing capacity depends on tree age, and about 50% of trees in China were of bearing age. The yields of some older orchards were 15 times average yields. The main reason for low, irregular cropping at low latitudes is vegetative growth in the 1–3 months before panicle formation in winter and, subsequently, poor flowering in spring (Menzel 1983). At higher latitudes there can also be the problem of poor fruit set (Menzel 1984).

The lychee inflorescence is formed on terminal branches and is a many-branched panicle which, depending on the cultivar and growing conditions, may vary in length from 10 to 40 cm (Menzel 1984). Panicles bear hundreds of yellowish white flowers, in a series of male and female flowering. Cultivars with many female flowers have the potential to be high yielding. Limited information from China indicates that fruit set was very poor in Souey Tung lychee when the proportion of female flowers fell below 8% (Zhuang *et al.* 1983). Excessive male flowering has also been considered to reduce yield in cashew and mango (Singh 1954; Damodaran *et al.* 1965; Thimmappaiah and Suman 1987). In mango, yields were reduced when the proportion of female flowers fell below 4–10%.

Fruit drop in lychee occurs from fruit set to fruit maturity, with a peak in the first month after fruit set. The amount of drop varies greatly with cultivar, and in some instances nearly all fruit may drop, seriously reducing cropping (Yuan and Huang 1988).

This paper describes the pattern of panicle and flower development of lychee cultivars in subtropical Queensland. The importance of female flowering, fruit set, and fruit drop on yield were determined. The relationship between female flowering and winter temperatures was also assessed, because glasshouse studies (Menzel and Simpson 1991*b*) and some preliminary field studies in China (Zhuang *et al.* 1983) indicated that female flowering was greater at low temperatures. The approach of relating fruit set to sex ratios is the same as that of Chadha and Rajpoot (1969), although they worked with Indian cultivars and did not relate flowering to weather.

Materials and methods

Description of orchards

Experiments were conducted near Nambour in subtropical Queensland (lat. 27°S.) between April 1989 and January 1990, on 8–10-year-old lychee trees: cv. Tai So at 3 sites, cv. Bengal at 4 sites, cv. Kwai May Pink at 2 sites, cv. Salathiel at 3 sites, and cv. Wai Chee at 2 sites. Trees were managed as commercial crops with respect to irrigation, nutrition, and weed and pest management (Menzel *et al.* 1988). Weather data were collected at each site during the experiment (Table 1).

Measurements

A record was kept of the stage of panicle and flower development every 1–2 weeks after the first visible signs of panicle emergence until the start of flowering, and then weekly during anthesis. The developmental stages were: 0, bud in rest with no sign of growth; 1, first indication of bud development with bud beginning to swell; 2, obvious bud growth with primary branch of panicle elongating; 3, primary branch continuing to elongate and secondary branches appearing; 4, secondary branches elongating; 5, tertiary branches elongating and/or floral clusters appearing; 6, floral buds swelling and individual flowers distinguishable; 7, stigmas protruding from female flowers; 8, first flowers opening; 9, peak of flower opening; and 10, end of flower opening. The development of the panicles against time was plotted by regression analysis. None of the terminal buds tagged reverted to vegetative growth. Measurements were also made of the number of male and female flowers opening at weekly intervals, and of panicle stalk dry weight (excluding flowers and fruit) and length at the end of flowering. Panicles were tagged at the start of measurement and covered with paper bags at the start of flowering, to collect flowers weekly for counting in the laboratory. A separate set of unbagged panicles was tagged for each orchard, and the numbers of fruit per panicle were recorded 2 weeks after last flower collection (2–3 weeks after last flower opening) and again at harvest. Data are the means of 40 north-facing branches divided among 4 trees for each orchard. Yields per tree were also taken on 5–10 trees at each orchard.

Statistical analysis

Least square ANOVA was used to isolate the effects of sites and cultivars and their interactions, using the means of the replicates (4 or 5–10 trees) as the raw data. Orchard was not a factor in the analyses and is included in the error term. A significant interaction between sites and cultivars was found for most variables, indicating that the site influenced the response of the cultivars. Consequently, the effects of orchard (combined effects of site and cultivar) were tested by a 1-way ANOVA (orchard only).

To ascertain whether 1 or more phenological stages were governing final yield, the relationships between the number of fruit per panicle at harvest and fruit drop, fruit set, and numbers of female flowers were determined by regression analysis. The relationship between the number of female flowers, the per cent of female flowers setting fruit or fruit drop, and seasonal progressions in temperatures and rainfall, were also determined.

Results

Weather

Minimum temperatures were about 2°C higher at Beerwah than at the other sites during June–September (Table 1). In October–December, minimum temperatures at Yandina, Eudlo and Beerwah were 1–2°C lower, and maximum temperatures at Caboolture were 1–2°C

Table 1. Mean monthly minimum and maximum daily temperatures (°C) and total monthly precipitation (mm) at the four lychee sites during the experiment

	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
				Yandina					
Max. temperature	26.1	22.4	20.4	19.1	21.0	24.2	26.9	24.8	26.4
Min. temperature	17.5	13.9	8.6	7.1	5.3	8.6	13.5	15.6	16.1
Precipitation	641	59	71	68	145	33	52	65	101
				Eudlo					
Max. temperature	25.2	23.7	19.7	18.7	20.6	23.8	27.0	25.1	26.2
Min. temperature	16.6	15.0	9.3	7.4	5.9	8.6	13.2	14.9	15.6
Precipitation	1083	232	116	145	128	24	32	363	179
				Beerwah					
Max. temperature	25.4	22.8	19.7	19.0	20.8	24.5	28.0	26.0	27.6
Min. temperature	17.5	15.5	11.1	9.2	7.9	10.9	15.0	15.8	16.7
Precipitation	875	339	51	59	74	7	20	91	33
				Caboolture					
Max. temperature	26.5	23.1	20.8	20.1	20.4	25.7	29.1	27.0	28.5
Min. temperature	16.2	14.2	8.9	7.2	5.4	8.0	12.2	14.4	15.3
Precipitation	869	293	38	33	61	8	73	161	91

higher. Eudlo received about 2–3 times as much rain as the other sites during the experiment. Higher rainfall was received at Eudlo, Beerwah and Caboolture in May; at Eudlo in June–July; at Yandina and Eudlo in August; at Eudlo in April and November; and at Yandina, Eudlo and Caboolture in December.

Panicle and flower development

The development of the panicles was plotted against time as linear or quadratic regressions, with $R^2 > 0.98$ ($P<0.001$) (Fig. 1). At all sites, Tai So was the first cultivar to initiate panicles, with panicles emerging in late May. Tai So was followed by Bengal, Kwai May Pink, Salathiel, and Wai Chee (5–7 weeks later). It was not possible to measure exactly the period of panicle development in the cultivars, since microscopic measurements of floral initiation were not made, and cultivar Tai So was tagged at about stage 1 compared to stages 1–2 in the other cultivars.

Flower anthesis

Tai So usually flowered 3–4 weeks earlier than the other cultivars (Fig. 2). Cultivars also varied in the period of anthesis. Tai So had a longer period of flowering (4 weeks) than Bengal (2–3 weeks), Kwai May Pink (3 weeks), Salathiel (1–3 weeks), and Wai Chee (3 weeks). Three types of flowers occurred in succession on the same tree, but not always on the same branch at any one time. They were, in order of appearance, male, hermaphrodite with non-dehiscent anthers (functional female), and hermaphrodite with abortive ovary (functional male). Male flowers tended to dominate early flowering, usually with a mixture of male and female flowering at later stages (Fig. 2).

The number of flowers per panicle opening during each week of anthesis varied with cultivar: Tai So, 461–802; Bengal, 434–1050; Kwai May Pink, 281–92; Salathiel, 184–849; and Wai Chee, 161–75.

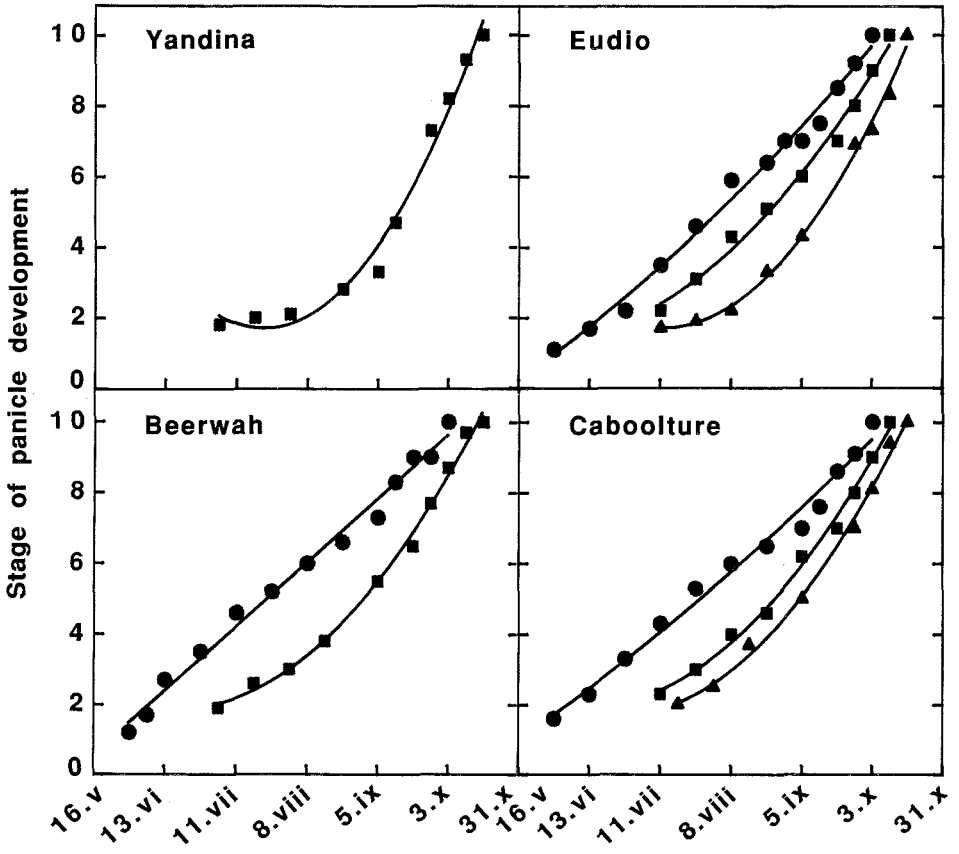

Fig. 1. The inflorescence development of lychee cvv. Tai So (●), Bengal (■), and Wai Chee (▲), in the 14 lychee orchards at four sites. Data are the means of 40 branches divided among four trees. Average s.e. of mean is ± 0.2. The development of the panicles against time are plotted as linear or quadratic regressions. At Yandina, cv. Salathiel had a similar rate of development to cv. Bengal. At Eudlo and Caboolture, cv. Salathiel had a similar rate of development to cv. Wai Chee. At Beerwah and Caboolture, cv. Kwai May Pink had a similar rate of development to cv. Bengal. See Materials and methods for stages of inflorescence development.

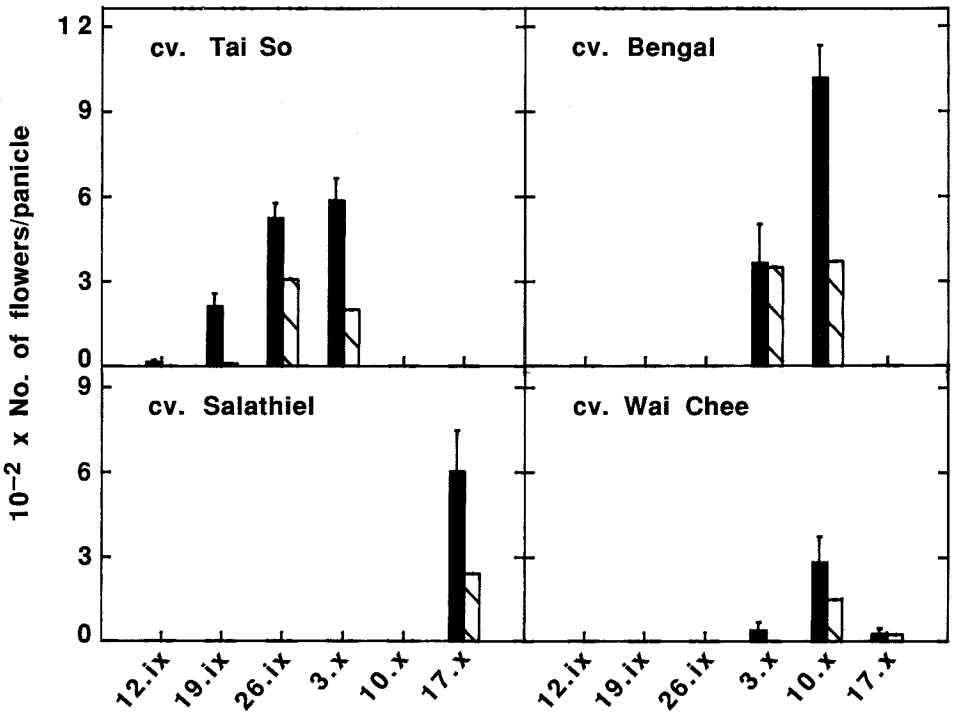

Fig. 2. The number of male (solid bars) and female flowers (striped bars) per panicle at weekly intervals for cvv. Tai So, Bengal, Salathiel, and Wai Chee at Eudlo. Data are the means of 40 branches divided among 4 trees. Vertical bars indicate s.e. for number of male flowers. Cultivar Tai So had the same period of anthesis at Beerwah and Caboolture as at Eudlo. Cultivar Wai Chee at Caboolture and cv. Kwai May Pink at Beerwah and Caboolture had the same period of anthesis as cv. Wai Chee at Eudlo. Cultivar Bengal flowered 8–17 October at Beerwah and 10–17 October at Yandina. Cultivar Salathiel flowered 10–17 October at Yandina and 10–17 October at Caboolture.

Table 2. Flowering and fruiting of lychee cultivars in subtropical Australia

Data are the means of 40 branches divided among four trees except for yields which are means of 5–10 trees

Cultivar	No. of flowers per panicle			Female flowers (%)	Panicle length (cm)	Panicle stalk dry wt (g)	No. of fruit per panicle after flowering	Female flowers setting fruit (%)	No. of fruit per panicle at harvest	Fruit drop (%)	Yield (kg/tree)
	Male	Female	Total								
						Yandina					
Bengal	499	370	869	43	12.2	1.47	21.8	6.1	10.3	52	2.8
Salathiel	616	245	861	32	11.6	1.35	16.0	7.2	12.0	24	1.5
						Eudlo					
Tai So	1329	526	1854	28	25.9	3.04	17.0	3.4	10.0	40	21.6
Bengal	1380	720	2100	35	17.6	3.49	14.5	2.1	5.8	57	24.9
Salathiel	604	245	849	31	19.5	1.74	17.0	8.4	9.5	46	7.5
Wai Chee	347	179	526	34	10.7	1.16	7.5	4.7	4.3	49	5.3
						Beerwah					
Tai So	2203	1121	3324	33	32.0	6.89	32.8	3.1	21.8	31	37.9
Bengal	1492	518	2010	27	18.2	3.52	26.3	5.4	7.3	72	35.1
Kwai May Pink	690	153	843	18	14.0	1.98	17.3	11.3	7.3	51	15.3
						Caboolture					
Tai So	2530	681	3211	21	23.2	4.71	22.0	3.6	8.0	62	30.1
Bengal	1613	401	2014	20	17.1	4.50	22.3	9.2	8.3	56	24.6
Kwai May Pink	733	142	875	17	13.7	1.88	18.0	14.7	5.0	71	19.0
Salathiel	457	94	551	18	14.0	1.18	17.5	19.5	6.5	67	17.7
Wai Chee	387	97	484	21	13.0	1.16	8.8	11.0	6.0	34	18.6
l.s.d ($P = 0.05$)	527	245	717	1	3.8	1.16	10.3	7.3	5.5	2	11.2

Panicle length and panicle stalk dry weight

Cultivars Tai So and Bengal generally had large panicles compared to cvv. Kwai May Pink, Salathiel and Wai Chee (Table 2). The only exceptions were cv. Bengal at Yandina, which had small panicles and cv. Salathiel at Eudlo, which had large panicles. There was a strong correlation between panicle length and panicle stalk weight across all orchards (R^2 = 0.71; P = 0.001) (Fig. 3*a*).

Number of flowers and proportion of female flowers

Total number of flowers per panicle ranged from 484 (cv. Wai Chee at Caboolture) to 3324 (cv. Tai So at Beerwah) (Table 2). Generally, Tai So and Bengal had 1800–3400 flowers/panicle, compared with 400–900 on the other cultivars, except for Bengal at Yandina, which had <1000 flowers/panicle. The proportion of female flowers varied with orchard (Table 2). The highest proportion of female flowers (>40%) occurred on cv. Bengal at Yandina, and the lowest (17–18%) on cv. Kwai May Pink at Beerwah and Caboolture and cv. Salathiel at Caboolture. There was a weak correlation between the number of female flowers per panicle and average maximum temperatures during inflorescence stages 3–5 (appearance of the secondary branches to appearance of flower clusters) (Fig. 3*b*). The inclusion of site, minimum temperature, and rainfall did not improve the regression (P>0.05).

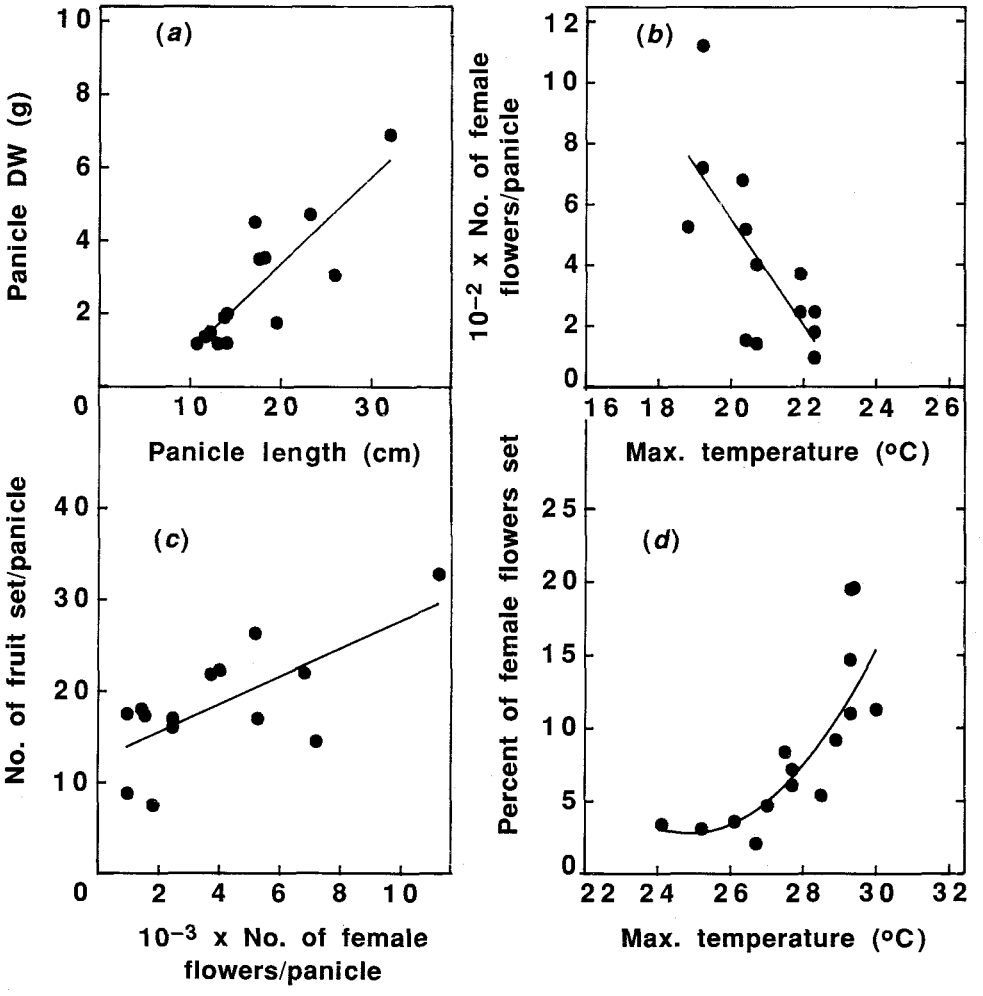

Fig. 3. Relationships between: (*a*) panicle stalk dry weight (DW) and panicle length (L) (DW = 1.42 + 0.24L; R^2 = 0.71; P = 0.001); (*b*) number of female flowers per panicle (FF) and average maximum temperature during stages 3–5 of inflorescence development (T_i) (FF = 4031 – 175T_i; R^2 = 0.56; P = 0.002); (*c*) number of fruit set per panicle (FS) and number of female flowers per panicle (FF) (FS = 12.51 + 0.015FF; R^2 = 0.48; P = 0.006); and (*d*) the percentage of female flowers setting fruit (F) and average maximum temperatures during fruit set (T_f) (F = 298.4 – 23.77T_f + 0.478T_f^2; R^2 = 0.67; P = 0.002), in the 14 lychee orchards. Data are the means of 40 branches divided among 4 trees.

Number of fruit after flowering

Fruit set was assessed 2 weeks after the last flowers were sampled. As samples were collected weekly, counts of fruit set were actually made 2–3 weeks after last flower opening. The number of fruit per panicle 2–3 weeks after the end of flowering was greatest in cv. Tai So at Beerwah and lowest in cv. Wai Chee at Eudlo and Caboolture (Table 2). There was a weak correlation between the number of fruit per panicle and the number of female flowers per panicle (Fig. 3*c*). Although fruit set expressed as a percentage of the number of female flowers was significantly related to the number of female flowers per panicle ($R^2 = 0.66$; $P = 0.003$) and average maximum temperatures during fruit set (Fig. 3*d*), a step-up multiple regression indicated that only maximum temperatures significantly affected the percentage of female flowers setting fruit. Rainfall during fruit set ranged from 0 to 9 mm/week and did not significantly ($P>0.05$) affect fruit set.

Number of fruit at harvest

The number of fruit per panicle at harvest ranged from about 4 to 12 (Table 2). The only exception was on cv. Tai So at Beerwah, with 22 fruit/panicle. There was no significant ($P>0.05$) relationship between the number of fruit at harvest and the number of fruit per panicle after flowering across the different orchards. Fruit drop (as a percentage of fruit set per panicle) ranged from 24 to 72% (Table 2) and was not significantly ($P>0.05$) related to the number of fruit set per panicle, average maximum temperatures, or rainfall in the month after fruit set.

Tree yield

Fruit yield ranged from 1.5 to 37.9 kg/tree and was not significantly ($P>0.05$) related to the number of fruit harvested per panicle because of variations in the number of terminal branches flowering and, hence, carrying fruit in each orchard (Table 2).

Discussion

Panicles emerged between May and July when mean monthly maximum temperatures in the preceding 4 weeks ranged from 19.9 to 26.5°C and minimum temperatures were 7.9–17.5°C. Controlled environment studies showed that lychee cultivars were floral at 15°C day temperature, mixed at 20°C, and vegetative at 25°C and 30°C (Menzel and Simpson 1988; Menzel *et al.* 1989). In the present experiment most of the cultivars flowered heavily (>70% of terminal branches floral), and most of the panicles were leafless.

The number of female flowers per panicle decreased as average maximum temperatures during flower development increased from 18 to 23°C. Similarly, Menzel and Simpson (1991*b*) indicated that female flowering decreased as day temperatures increased from 15 to 30°C. The order for decreasing proportion of female flowers across temperature was Wai Chee > Bengal > Souey Tung > Tai So > Kwai May Pink. The effect of temperature on sex ratio is not easy to ascertain in the present experiment because the cultivars vary in the number or proportion of female flowers at any one temperature regime. Tai So produced flowers at cooler day temperatures than the other cultivars, and this resulted in the proportion of female flowers on Tai So being higher than expected from cultivar performance under glasshouse conditions, while the proportion on Salathiel and Wai Chee was lower than expected. As expected, the proportion of female flowers in Kwai May Pink was low, due to its predisposition to a low percentage of female flowers, and to its later development during warmer weather. Cultivar Bengal tended to be a midseason cultivar with a good proportion of female flowers (20–53%).

The number of fruit set per panicle increased as number of female flowers per panicle increased. Chadha and Rajpoot (1969) are 2 of the few researchers to demonstrate a relationship between fruit set and female flowering; Calcutta Late had 48.7% of female flowers and 23.2% of flowers setting fruit, while Dehradun had 19.8% of female flowers and 8.0% fruit set. When the difference in the proportion of female flowers was taken into account, there was only a slight effect of cultivar on fruit set (47.6 and 40.3% for Calcutta Late and Dehradun, respectively).

Anthesis was longest for cv. Tai So at maximum temperatures of 24.1–26.1°C, compared to 25.2–29.3°C for other cultivars. Controlled temperature experiments showed that anthesis was reduced from 19 days at 15°C to 11 days at 30°C (Menzel and Simpson 1991*b*); however, the number of flowers opening each week in our experiment was more related to the total number of flowers. The percentage of female flowers setting fruit increased at higher temperatures, in agreement with glasshouse studies by McConchie and Batten (1989).

Chadha and Rajpoot (1969) indicated that initial fruit set in 5 Indian cultivars was very high (71–181 fruit/panicle), but very few fruit were retained at maturity (2–8 fruit/panicle). McConchie and Batten (1989) suggested that the most appropriate time for fruit to be considered set is when most fruit left on a panicle reach maturity. When they pollinated all of the female flowers on panicles of Bengal lychee, 9% of flowers produced mature fruit. In our experiment, 0.8–6.8% of female flowers carried fruit to maturity, and set was higher in the later cultivars (Kwai May Pink, Salathiel and Wai Chee). These values are generally greater than the rate of fruit set reported by Chadha and Rajpoot (1969) (0.1–0.2% female flowers) in India, and by Zhuang *et al.* (1983) (0.05–1.6% female flowers) in China, although they are similar to the rate of fruit set (3.4–6.3% female flowers) reported in Taiwan by Chen (1991).

Factors possibly associated with fruit drop include poor pollination (McConchie and Batten 1989), water or nutritional stress (Menzel 1984; Menzel and Simpson 1987), and insect damage (Waite 1990). Our data do not separate these factors, which presumably varied with orchard. McConchie and Batten (1989) claimed that pollination limited yield in lychee, although bees are active pollinators (King *et al.* 1988). Even with hand pollination, only 9% of female flowers carried fruit to harvest, suggesting that other factors were responsible for the loss of most flowers or fruit. McConchie and Batten (1989) cannot claim that hand pollination was responsible for increased fruit set unless a set of control open-pollinated trees was included. The maximum percentage of female flowers carrying a fruit to maturity in our experiment and in Chen's (1991) was about 55–80% of that reported by McConchie and Batten. Waite (1990) showed that spotting bugs (*Amblypelta nitida* and *A. lutescens*) may be the most important factor inducing lychee fruit abscission in some areas, accounting for 24.8–98.5% of green fruit drop in several locations in Queensland.

Yields ranged from 1.5 to 37.9 kg/tree, equivalent to 0.2–5.7 t/ha at a density of 150 trees/ha, and are close to those from trees of similar age in 2 earlier studies in subtropical Australia (Menzel *et al.* 1986; Menzel and Simpson 1991*a*).

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