

Effect of Climate Variability and Degree-Day on Development, Yield and Quality of Shogun (*Citrus reticulata* Blanco) in Southern Thailand

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ABSTRACT

Climatic factors and degree-days are normally important in the development, yield and quality of fruits leading to commercial value. However, there has been no investigation of this aspect for shogun (*Citrus reticulata* Blanco). Hence, the fruit development, yield and quality of shogun under the influence of climatic factors were investigated using the framework of a quadrat cube (0.5 × 0.5 × 0.5 m) during two consecutive years (2011–2012). Forty 8-year-old uniform trees, field grown in Yala and Pattani provinces were used. The experiment was designed as a completely randomized design. It was evident that the weather conditions between 2011 and 2012 were different, with the rainfall in 2012 lower. The results showed that fruit yields in Pattani in 2011 and 2012 (38.89 and 36.69 kg per tree, respectively) were significantly ($P \leq 0.01$) higher than those in Yala (27.74 and 18.53 kg per tree, respectively). Comparing 2011 and 2012, fruit yields in Pattani and Yala decreased 5.65 and 33.20%, respectively. The fruit diameters of shogun fruit in Pattani in 2011 and 2012 were 5.63 and 5.62 cm, while in Yala they were 5.02 and 4.98 cm, respectively, with growing degree-days of 3,387 and 2,989, and 3,153 and 2,780, respectively. The fruit quality in Pattani in 2011 and 2012 was better than in Yala based on the weight of fruit, peel and juice and peel thickness, whereas the total soluble solids in Pattani were lower than in Yala. Furthermore, the color of the rind in Pattani was greener than that in Yala. It was suggested that a decrease in the rainfall and soil moisture caused a negative impact on the fruit development, yield and quality of shogun in Yala. Hence climatic variability and degree-days influenced the development, yield and quality.

Keywords: degree-day, fruit development, fruit quality, climate, *Citrus* sp.

INTRODUCTION

Environmental variables, especially temperature, are the key factor which affects plant growth, development and productivity (Atkinson and Porter, 1996; Spiegel-Roy and Goldschmidt, 1996; Wheeler *et al.*, 2000; Kaleem *et al.*, 2010). Differences in the development, yield and quality of fruit attributes in varying seasons and locations

might be due to the different climatic conditions that are based on the temperature prevailing during the crop life cycle (Killi and Altunbay, 2005; Demirkeser *et al.*, 2009; Dorji and Yapwattanaphun, 2011; Chelong and Sdoodee, 2012). Climate is interrelated with citrus quantity and quality; in the subtropical region; the fruit growth rate is rapid, but the fruit quality of oranges and mandarins is poor, with peel color typically green and the juice

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color a pale, light yellow (Davies and Albrigo, 1994; Makinde *et al.*, 2011). Moreover, the total soluble solids (sugars) and acids tend to be low due to high average temperatures throughout the year which cause respiratory metabolism of sugar and acids (Davies and Albrigo, 1994; Davies, 1997). Growing degree-days (GDD) or heat units data seem to correlate reasonably well with dates of fruit maturation. Differences between early and late maturation dates are believed to reflect differences in temperature (Reuther, 1973). The thermal sum for the fruit growth and maturation of 'Folha Murcha' orange ranged from 4,462 to 5,090 GDD (Stenzel *et al.*, 2006). In the state of São Paulo, Brazil, orange varieties require between 2,500 and 3,600 GDD for fruit to attain maturation (Ortolani *et al.*, 1991). The objective of this work was to determine the climatic variability in terms of degree-days on the development, yield and quality of shogun fruits in southern Thailand.

MATERIALS AND METHODS

The effect of climate and degree-days on shogun development, yield and quality in southern Thailand were studied in two farmer orchards, one in Yarang district, Pattani province and the other in Yaha district, Yala province. The assessment used a framework of quadrat cube plots ($0.5 \times 0.5 \times 0.5$ m) as shown in Figure 1,

over two consecutive years (2011–2012). Eight-year-old shogun trees (4×6 m spacing) were used for the study. The experiments was designed as a completely randomized design; with 40 trees at each location.

Fruit development, yield and quality measurements

Five pieces of fruit per quadrat cube were randomly collected and their fruit diameters measured with a digital caliper 8 mth after bloom. The fruits were harvested in 2011 and 2012. Total soluble solids (TSS) were determined with a hand refractometer (Model ATC-1E; VWR International Ltd; Chicago, IL, USA). The fruit weight and peel thickness were determined by sampling each piece of fruit and the result was reported as the mean \pm SD. The rind color was determined on a 1–7 scale (1–4 = light to dark green; 5 = orange; 6 = dark orange; 7 = reddish orange). Fruit yields in both locations were recorded in 2011 and 2012.

Climatic factors

Data on rainfall, evaporation, soil moisture and temperature were recorded using a data logger and accumulated growing degree-days (GDD) at both orchard sites were also assessed.

Experimental design and data analysis

The experiment was carried out using



Figure 1 Quadrat cube ($0.5 \times 0.5 \times 0.5$ m) placed on a sample shogun tree.

a completely randomized design layout. Data were analyzed using the SAS statistical software version 9.1.3 (SAS Institute; Cary, NC, USA) and the comparison of means was carried out using Duncan's multiple range test. Significance was tested at the $P \leq 0.01$ level.

RESULTS AND DISCUSSION

Fruit development

The fruit development in 2011 and 2012 was significantly different between the locations. In 2011 at the Pattani site, the average fruit diameters after bloom at 1, 2, 3, 4, 5, 6, 7 and 8 mth were 2.01, 3.57, 3.87, 4.34, 5.48, 5.58, 5.59 and 5.63 cm, respectively, whereas at the Yala site, they were 1.87, 3.04, 3.15, 4.02, 4.56, 4.86, 4.87 and 5.02 cm, respectively (Figure 2). In 2012, at Pattani, the average fruit diameters after bloom at 1, 2, 3, 4, 5, 6, 7 and 8 mth were 1.91, 3.19, 3.47, 4.17, 5.39, 5.57, 5.58 and 5.62 cm, respectively, while at Yala, they were 1.77, 2.76, 3.01, 3.68, 4.23, 4.74, 4.87 and 4.98 cm, respectively (Figure 3). The numbers of days for fruit growth and maturity in 2011-2012 at Yala were shorter than those at the Pattani site by about 14–21 d. It seemed that fruit development was accelerated by

high temperature (Figures 2, 3 and 7). In addition, it may have been due to several factors such as rainfall, evaporation and soil moisture with a water deficit effect on citrus fruit growth (Figure 4, 5 and 6). Fruit sizes tend to be reduced by water deficits because of a shorter fruit growth period (Salter and Goode, 1967). Volpe (1992) reported that in the state of São Paulo, Brazil, there are maturation season differences for citrus fruits among many regions due to altitude and latitude, which are conditioning factors of the temperature regime. Similarly, Cooper *et al.* (1963), studying 'Valencia' orange in the USA, verified that citrus fruits reach the maturation index (based on fruit size, rind color, soluble solids and titrations acid) more quickly in regions with higher temperatures. Temperature and plant development are related by the thermal summation or accumulative growing degree-days (GDD) for the plant cycle to reach a phenological stage (Souza, 1990). Therefore, the effect of thermal summation on fruit yield and quality of shogun is shown in Table 1. In 2011 and 2012, GDD values at Pattani were 3,387 and 2,989 and at Yala were 3,153 and 2,780, respectively (Figure 8), which were similar to values reported by Ortolani *et al.* (1991).

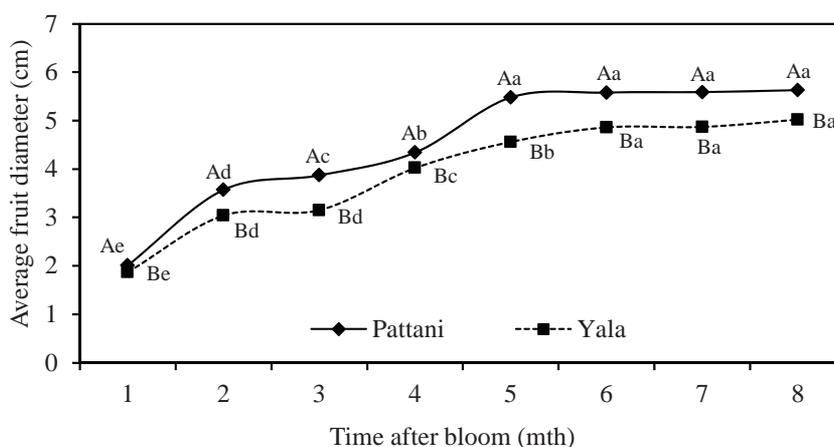


Figure 2 Shogun fruit diameter in Pattani and Yala orchards in 2011. For each site, mean fruit diameters with different first capital letters (same month) and second lowercase letters (between locations) are significantly different ($P \leq 0.01$).

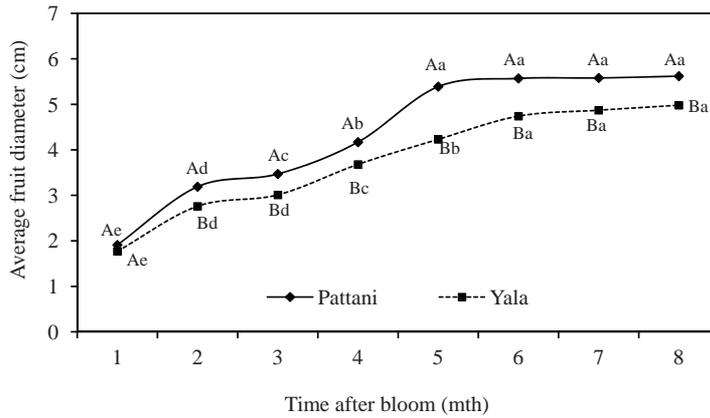


Figure 3 Shogun fruit diameter in Pattani and Yala orchards in 2012. For each site, means with different capital first letters (same month) and lowercase second letters (between locations) are significantly different ($P \leq 0.01$).

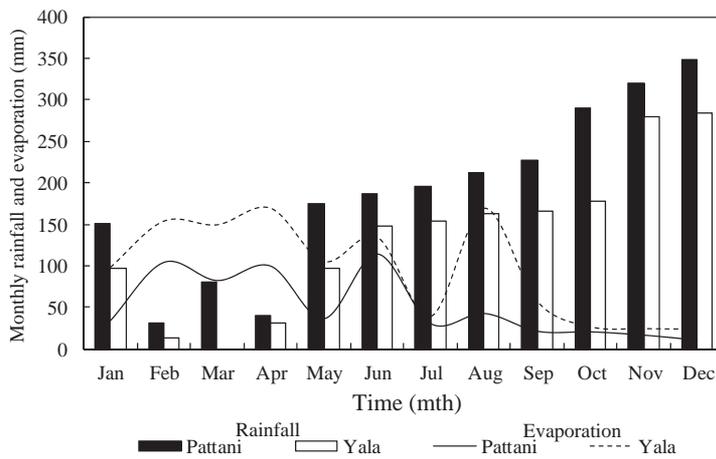


Figure 4 Monthly rainfall and evaporation in Pattani and Yala provinces in 2011.

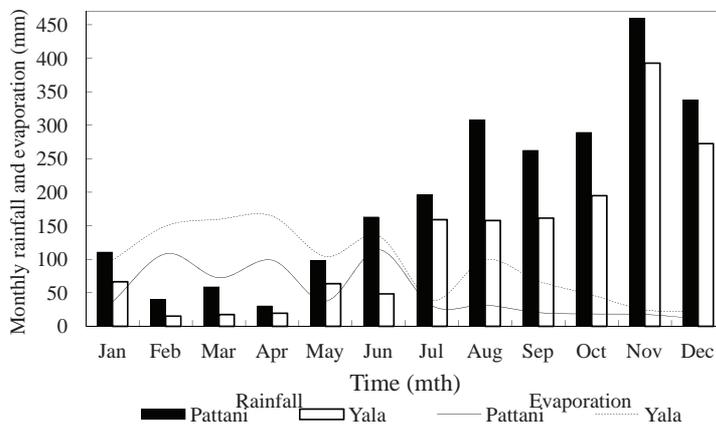


Figure 5 Monthly rainfall and evaporation in Pattani and Yala provinces in 2012.

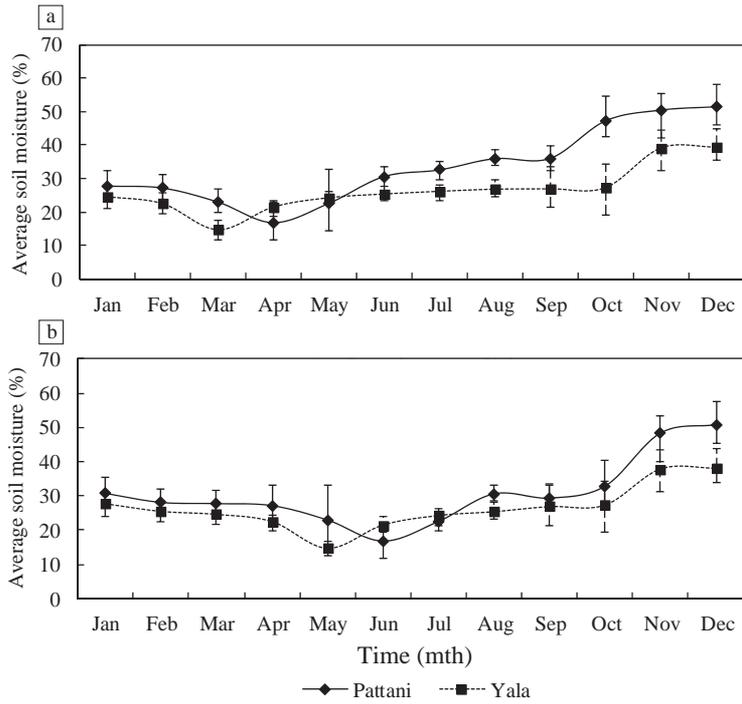


Figure 6 Average soil moisture content in Pattani and Yala provinces: (a) 2011; (b) 2012. The vertical bars represent the standard deviation of the mean ($P = 0.01$)

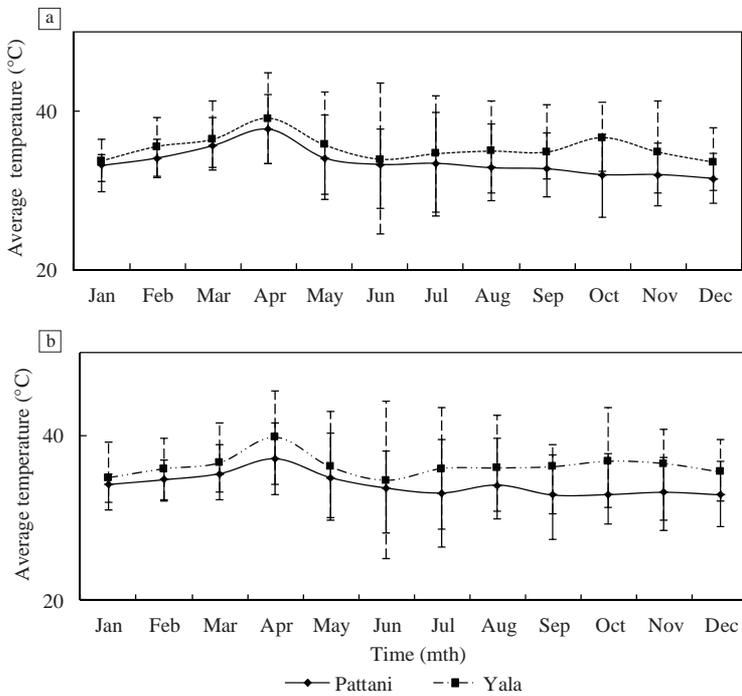


Figure 7 Average temperature in Pattani and Yala provinces: (a) 2011, (b) 2012. The vertical bars represent the standard deviation of the mean ($P \leq 0.01$)

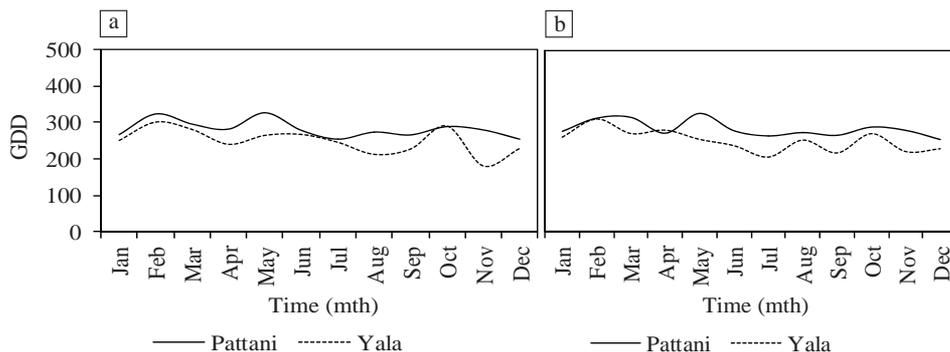


Figure 8 Average growing degree-days (GDD) in Pattani and Yala provinces: (a) 2011; (b) 2012.

Fruit yield and quality

The average yield of shogun fruit in Pattani and Yala differed significantly between 2011 and 2012 (Table 1), with decreases of 5.65 and 33.20%, respectively. It has been reported that temperature, rainfall and evaporation affect citrus yield (Downton and Miller, 1993; Shellie and Mangan, 1994; Ishfaq *et al.*, 1999; Tubiello *et al.*, 2002). Zekri and Rouse (2002) reported that increased temperature due to global warming may reduce citrus yield by 25%. García-Tejero *et al.* (2010) reported that a decrease of 50% in crop evapotranspiration may reduce the citrus yield by about 10%. This indicates climatic variability affects the citrus fruit yield (Yakushiji *et al.*, 1996). Water stress and high temperature have been reported to influence citrus growth and fruit yield (Ginestar and Castel, 1996) and a similar effect has been reported in other citrus cultivars (Har-Even and Monselise, 1959; Kriedemann and Barrs, 1981). Numerous Navel orange were dropped and loosened when water stress occurred during fruit maturation (Kallsen and Sanden, 2011). Crop growth simulations have shown that rice yields decrease 9% for each 1°C increase in seasonal average temperature (Food and Agricultural Organization, 1996). These results suggest that climatic factors will be the main limitations on citrus yields in the future.

Fruit quality as measured by the TSS, weight of fruit, peel and juice, peel thickness and

rind color were different between Pattani and Yala (Table 1). Climatic factors have been reported to have an effect on citrus fruit quality (Reuther, 1973; Holland *et al.*, 2002). At the Pattani site, the TSS values were lower than those of Yala in both years. The high levels of rainfall and soil moisture in the maturation phase caused a decrease in the TSS as the start of new vegetative growth utilized a part of reserved carbohydrates and thus the TSS of the fruits might be decreased. The results are in accordance with Bakhshi *et al.* (1968) and Joolka and Awashti (1980) who reported that TSS increased only until maturity and then decreased. In contrast, in the current study, the weights of the fruit, peel and juice were reduced. At Yala, fruit development was accelerated to maturation, resulting in a rapid development phase which has been reported to have an effect on weight characteristics (Reuther, 1973). The peel thickness, at Pattani was higher than that of Yala, indicating that peel thickness is also affected by climate. Similarly, Cohen *et al.* (1972) reported that low average minimum winter temperatures resulted in thick-peeled fruit. The rind color is an important external characteristic, and it was affected by the climatic conditions. The fruit rind color from the Yala orchard was a lighter orange than that of the Pattani orchard. Spiegel-Roy and Goldschmidt (1996) reported that the rind color is also affected by temperature with peel color changed when the day temperature was

Table 1 Shogun fruit quality and crop load on yield in 2011 and 2012 at Pattani and Yala orchards.

Location	Pattani		Yala	
	2011	2012	2011	2012
Total soluble solids (°Brix)	10.50 ^b	12.15 ^a	11.50 ^b	12.63 ^a
Fruit weight (g)	136.23 ^a	130.05 ^b	113.63 ^a	98.57 ^b
Peel weight (g)	19.11 ^a	18.57 ^{ab}	15.67 ^a	14.59 ^b
Juice weight (g)	120.12 ^a	111.48 ^b	99.96 ^a	83.98 ^b
Peel thickness (mm)	2.69 ^a	2.64 ^{ab}	1.64 ^a	1.52 ^b
Rind color	4	4	5	5
Yield (kg per tree)	38.89 ^a	36.69 ^b	27.74 ^a	18.53 ^b
Decrease in yield (%)	5.65		33.20	

Rind color was determined on a 1–7 scale (1–4 = Light to dark green; 5 = Orange; 6 = Dark orange; 7 = Reddish orange).

^{a,b} = Significantly different ($P \leq 0.01$).

warmer than 35 °C but the temperature was cooler than 15 °C during the night. These conditions promote chlorophyll breakdown and carotenoid synthesis and the development of yellow and orange color (Davies and Albrigo, 1994). Hence, it was suggested that climatic factors and degree-days affected the fruit growth, yield and quality of shogun fruit and these factors need to be investigated further.

CONCLUSION

The weights of the fruit, peel and juice at Pattani and Yala in 2011 were higher than in 2012, but the color of the rind was not substantially different between the years with scores of 4 (green) and 5 (orange), respectively. The fruit yield from Pattani was higher than that from Yala with the 2011 and 2012 amounts being 38.89 and 36.69, and 27.74 and 18.53 kg per tree, respectively, which represented decreases of 5.65 and 33.20%, respectively. The lower rainfall, evaporation and soil moisture had a negative effect on the development, yield and quality of the shogun fruit in Yala. Thus, it was concluded that climate and degree-day factors had an effect on the development, yield and quality of shogun fruit in southern Thailand.

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