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Research Article

Climate-related Changes in Tropical-fruit Flowering Phases in Songkhla Province, Southern Thailand

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Abstract: Changes in the timing of plant phenological phases in response to anomalous climate variability and the ongoing anthropogenic climate change have recently been studied in southern Thailand. In this study, we showed the evidence of climate-related changes in flowering phases of 2 tropical-fruit species: mangosteen (*Garcinia mangostana* L.) and longkong (*Lansium domesticum* Corr.) during 2003-2012. The flowering dates of these tropical fruits recorded at Hat Yai district, Songkhla province and daily climate data were used to assess phenophase response to variations in rainfall and evaporation. With the observed changes in local climate conditions which are defining factors for phenological development of tropical fruits particularly in southern Thailand, the flowering dates of both tropical fruits during 2003-2012 have significantly delayed comparing with the regular pattern in the past. Paradoxically, below-than-normal rainfall was also found in the El Niño years, while La Niña years were found in opposite. In summary, rainfall variations in Hat Yai district, Songkhla province are associated with ENSO. It was evident that the flowering period of tropical fruits tended to shift to the second-half of the year instead of the first-half of the year as usual. The results revealed that, during 33 years (1980-2012), annual rainfall totals, the annual number of rainy days, relative humidity, maximum and minimum temperatures from the Thai Meteorological Department significantly increased by 29.5 mm/year, 0.83 day/year, 0.116 %/year, 0.033 and 0.035°C/year, respectively. These findings suggest that anthropogenically warm climate and its associated inter-annual variations in local weather patterns may to the great extent influence on tropical-fruit phenology and their responses to recent climate change seem to be complex and nonlinear. Therefore, further study is needed to shed more light on such causal-effect linkages and plausible underlying mechanisms.

Keywords: Climatic change, flowering, *Garcinia mangostana* L., *Lansium domesticum* Corr., phenology, tropical fruit

INTRODUCTION

Mangosteen and longkong are the high economical fruits in southern Thailand (Department of Agriculture, 2006). The productivity and quality of these fruits depend strongly on meteorological and growing conditions (Osman and Milan, 2006; Nakasone and Paull, 1998; Apiratikorn *et al*., 2012). Mangosteen is an evergreen tree of Southeast Asian origin and regarded as the world's best fruit flavor (Almeyda and Martin, 1976; Wiebel, 1993; SCUC, 2006). The flowering period of mangosteen is normally between February-April and harvesting period is between June-August (Boonklong *et al*., 2006; Apiratikorn *et al*., 2012). Sdoodee *et al*. (2010) showed that changes in rainfall distribution could affect year-to-year variations in flowering, productivity and quality of tropical fruits. Whereas, longkong is a tropical fruit which is increasing demand because of its juicy and, a pleasant taste as well as enrichment of various nutrients (Sapii *et al*., 2000). In southern Thailand, the flowering period of longkong normally takes place between March-April and harvesting period is between July-September (Department of Agriculture, 2006). However, Uraipan (2009) reported that climate variability in southern Thailand may cause off-season flowering of longkong and change in rainfall distribution may shift flowering of longkong to the second-half of year.

Phenology has recently emerged as an important focus for ecological research (Schwartz, 2003), because phenological phenomena are visible and their responses are closely related to changing climate (Parmesan and Yohe, 2003). The increased attention is being paid to the analysis of phenological variation and growth length in the context of climate change (Walther *et al*., 2002). Many observations on phenological shifts in

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response to climate change have been reported from different parts of the globe, such as in Europe (Sparks and Menzel, 2000), United States (Parmesan and Yohe, 2003), Australia (Chambers, 2009) and East Asia (Sthapit *et al*., 2012). In Europe, for example, the lengthening of growing season has advanced in spring and has delayed in autumn, leading to the extension of growth period (Menzel and Fabian, 1999). Chmielewski and RÖtzer (2001) reported that spring events such as leaf unfolding or needle flush are particularly sensitive to temperature. Recent studies have further begun to consider changes in the timing of life-history events for one species relative to those of an interacting species (Durant *et al*., 2005). In addition, Peiling *et al*. (2006) reported that changes in timing of plant phenological phases are influenced greatly by monsoon-induced climate fluctuations.

Recent study has shown that Thailand has experienced significant country-wide warming over the last four decades and the extreme events associated with both the cold and warm tails of minimum and maximum temperature distributions have changed remarkably (Limjirakan and Limsakul, 2012). From the sub-national perspective, there is evidence that southern Thailand is prone to weather extreme events and hydro-meteorological disasters especially those associated with monsoon, the El Niño-Southern Oscillation (ENSO) and intense tropical cyclones (Singhratina *et al*., 2005; Juneng and Tangang, 2005; Lau and Nath, 2003; Limsakul *et al*., 2010). Limsakul *et al*. (2010) found that the Gulf of Thailand's western cost has experienced a wetter condition and increases in magnitude and frequency of more intense rainfall events. Therefore, one of consequences of such observed change is expected to have substantial effect on phenology within this region.

In this study, we investigated the responses of mangosteen and longkong to climate variability and change in Hat Yai district, Songkhla province, southern Thailand. The primary objective is to analyze mangosteen and longkong's flowering dates during 2003-2012 in relation to variations of local atmospheric variables such as rainfall, temperature and humidity as well as the ENSO index.

MATERIALS AND METHODS

The experiment was conducted at the experimental plot of Department of Plant Science, Faculty of Natural Resource, Prince of Songkla University (7°00' 14.02" N, 100°30' 1.75" E with altitude of 56 m above the sea level), Hat Yai district, Songkhla Province, southern Thailand. In this experimental plot, twenty trees of each species of mangosteen (*Garcinia mangostana* L.) and longkong (*Lansium domesticum* Corr.) were grown in 1997, with good management of cultural practices. Flowering Julian dates of both species were recorded every year from 2003 until 2012.

Daily meteorological data including rainfall, relative humidity and minimum and maximum temperatures at Hat Yai station during 1980-2012 were also used. The data were obtained from the archives of the Thai Meteorological Department (TMD), which data quality assurance is routinely performed both real-time and post-processing (Ouprasitwong, 2002; Agsorn, 2010). Rainfall data are daily recorded at 8 synoptic time intervals and the daily total for a particular day is then the amount collected over the 24 h period (Agsorn, 2010). Overall, the selected station records were on average 99% complete. All meteorological records were subjected to a visual examination for completeness, reasonableness and any obvious discontinuities. In addition, objective quality control approaches such as tests of spatial and temporal errors and data missing interpolation (Feng *et al*., 2004) were applied. Based on quality control testing, it is found that the quality of all meteorological records at Hat Yai station is good for climatological and trend analysis.

Linear trends of both meteorological and fruit flowering Julian date records were calculated by Kendall's non-parametric correlation analysis based slope estimator (Sen, 1968; Aguila *et al*., 2005; Zhang *et al*., 2005). The method is resistant to the effect of outliers in the series and accounts for time series autocorrelation. To further examine the relation between inter-annual variations in fruit flowering dates with the well-known mode of the global climate variability, the Multivariate ENSO Index (MEI) calculated as the first un-rotated Principal Component of six observed atmospheric and oceanic variables in the tropical Pacific (Wolter and Timlin, 1993, 1998) was used. The MEI integrates more information than other SOI or SST-based indices, it fully reflects the nature of the coupled ocean-atmosphere system and thereby is better for monitoring the ENSO phenomenon (Wolter and Timlin, 1993, 1998). The correlations of inter-annual variations between any pairs of mangosteen and lonkong flowering dates and MEI were evaluated with Kendall's nonparametric correlation coefficient (τ). This nonparametric method is free of the assumption that the data being analyzed have normal distribution with equal variances and so does not emphasize the extreme values (Limsakul *et al*., 2010).

RESULTS

The seasonal growth and phenological development of tropical fruits including mangosteen and longkong in the southern part of Thailand are correspondingly followed the annual rainfall pattern (Fig. 1). Normally, the flowering period takes place from March to April (Fig. 1) due primarily to a degree of rainfall deficit and water stress during pre-flowering

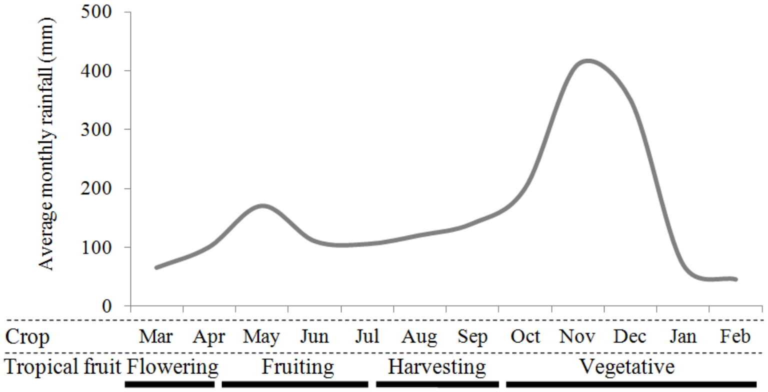

Fig. 1: The seasonal growth and phenological development of mangosteen and longkong in the southern Thailand in relation with the climatological monthly rainfall accumulation

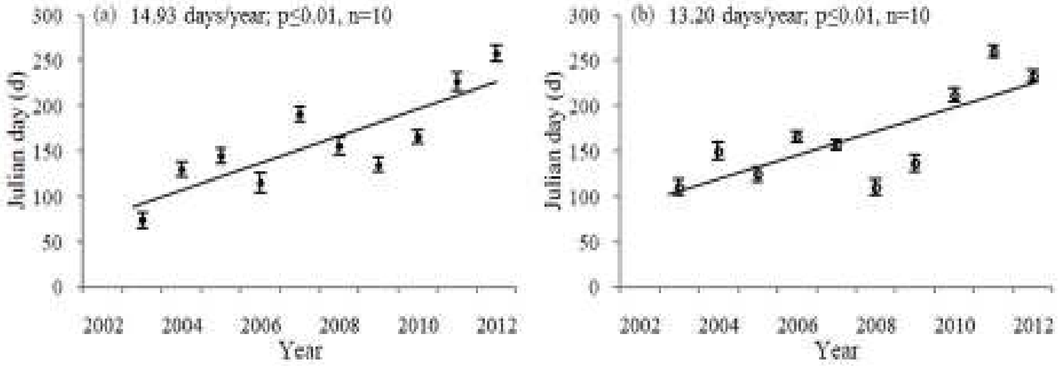

Fig. 2: Trends in averaged flowering dates of mangosteen (a) and longkong (b) during 10-year period (2003-2012) at Hat Yai district, Songkhla province, southern Thailand

months that reached a favorable threshold of flower induction. However, the observed data at the experimental site for the period 2003-2012 disclosed evidence of significant increasing trends in averaged flowering dates at the rates of 14.93 days/year for mangosteen and 13.20 days/year for longkong, respectively (Fig. 2). These results clearly indicate that mangosteen and longkong flowering phases in Hat Yai district, Songkhla province, southern Thailand have been remarkably delayed by about 4-5 months during 10-year period. Based on this observation, it was also apparent that the flowering period of both tropical fruits tended to shift to the second-half of the year instead of the first-half as usual. Another noteworthy feature was that mangosteen showed a greater delay in flowering dates than longkong (Fig. 3).

To explore what probably causes such a marked delay, we first looked at general trends in key meteorological variables (rainfall, humidity and temperature) that are often observed as important factors influencing plant phenology (Craufur and Wheeler, 2009; Cleland *et al*., 2007). From Fig. 4, it was evident that annual rainfall totals, the annual number of rainy days, relative humidity and maximum and minimum temperatures at Hat Yai station coherently exhibited significant increases at the rates of 29.5 mm/year, 0.83 days/year, 0.12%/year, 0.033 and 0.035°C/year, respectively. Trends detected in this study are consistent well with those previously documented by Limsakul *et al*. (2010) and Limjirakan and Limsakul (2012), emphasizing that climate at local scale in the east cost of the southern peninsula of Thailand have indeed shown a changing pattern toward warmer and wetter conditions. Although trends in fruit phenology and meteorological variables showed similar increasing patterns, no significant correlations at the 95% confidence level were found, when the mangosteen and longkong flowering dates and annual values of all meteorological variables for the period 2003-2012 were evaluated by Kendall correlation analysis. On the basis of this examination, it seems that changes in meteorological variables on the annual time scale do not contribute to the observed delay of mangosteen and longkong flowering. By investigating more details on meteorological changes during several periods of the year that correspond to seasonal development of fruit phenology, however, it was found that flowering Julian dates of both species

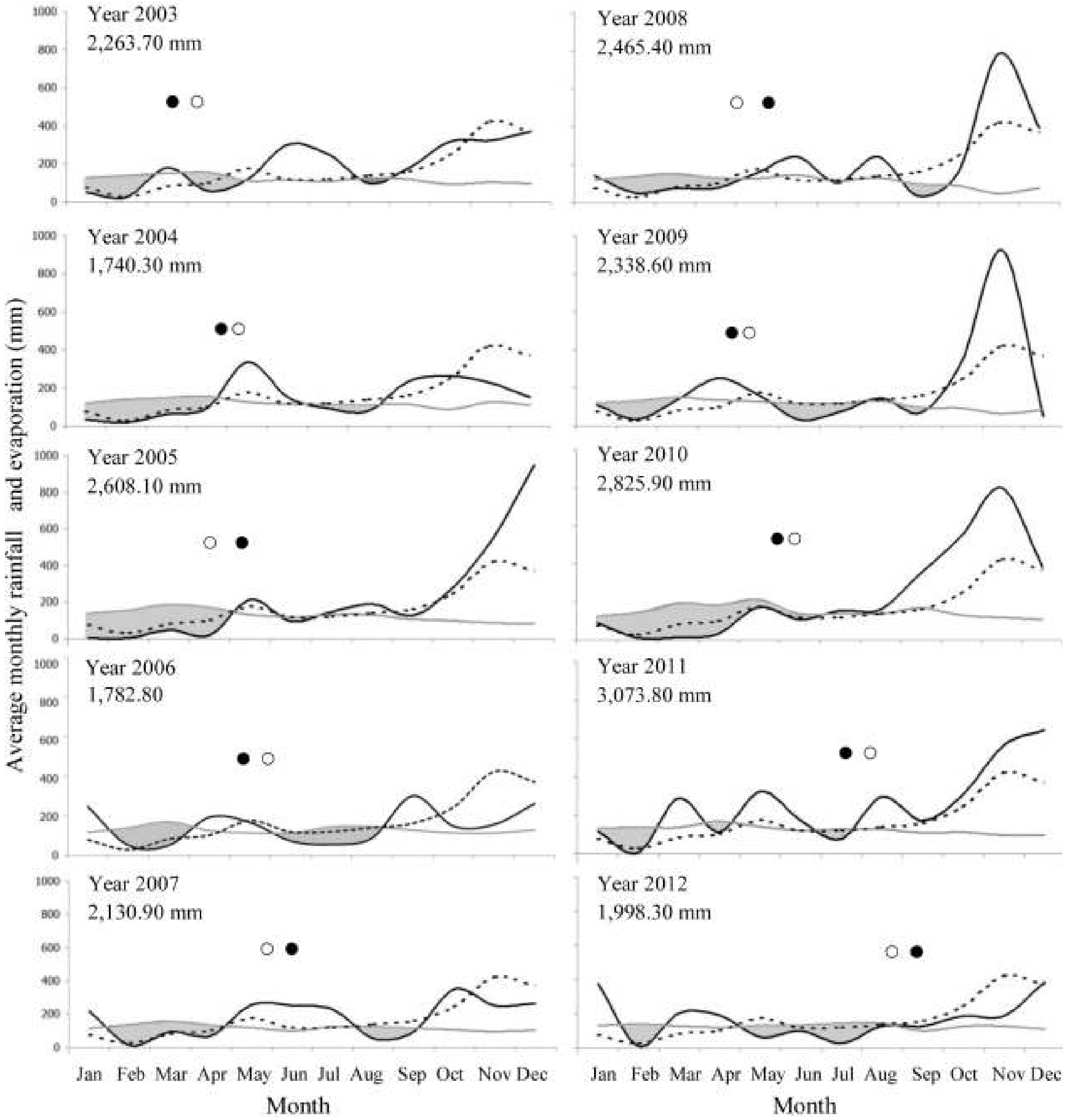

Fig. 3: Relevance between average monthly rainfall (30 year) (- -), annual monthly rainfall (–), annual monthly evaporation (–) and flowering date of mangosteen (●), longkong (o) and (■ water deficit period) during 2003-2012 in Hat Yai district, Songkhla province, Thailand

significantly correlated only with variations in January-March rainfall accumulation at the 95% level of confidence (Fig. 5). The onset of mangosteen and longkong flowering dates tended to advance (delay) in the years when rainfall accumulation during pre-flowering was lower (higher) than normal. Remarkable delays of flowering dates of both species in 2011 and 2012, for example, correspond well with anomalously accumulation of rainfall amounts during January-March period (Fig. 2 and 6). This relationship was also good agreement with the unprecedented increase in January-March rainfall accumulation at Hat Yai station especially the period since 1998 (Fig. 6). The exceptionally heavy rain event occurred in March 2011 when was usually one of hottest months was a recent example of unusually dry-period rainfall extremes, causing severe flash flooding over large areas of the southern Thailand (Limsakul *et al*., 2010). Based on these results, it appears that potential effects of climate phenomena on mangosteen and longkong phenology in southern Thailand mediate at least through variations in rainfall amount during pre-flowering period that, in turn, alleviate water stress as a critical factor for flowering induction.

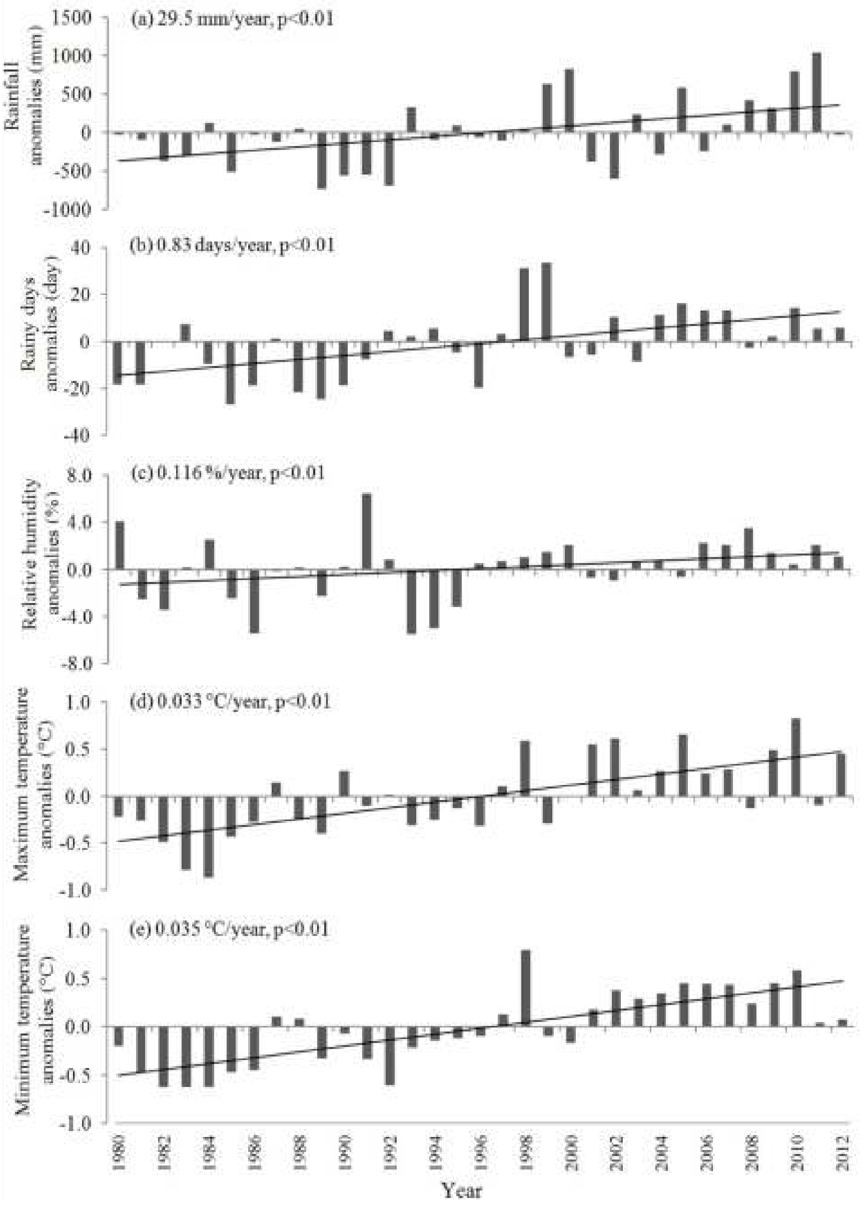

Fig. 4: Annual anomalies and trends of rainfall totals, (a) the number of rainy days, (b) relative humidity, (c) maximum temperature, (d) minimum temperature and (e) during 1980-2012 at Hat Yai station, Songkhla province, southern Thailand. Note that rainy days are defined as days with at least 1 mm of rain

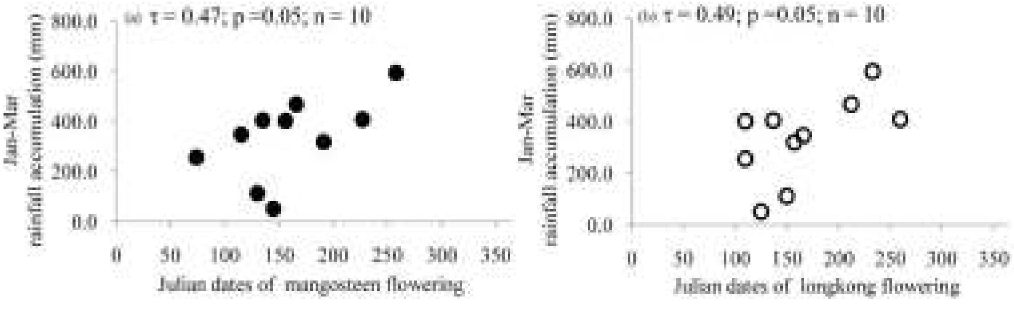

Fig. 5: Relationship between January-March rainfall accumulation and Julian dates of mangosteen flowering, (a) longkong flowering, (b) during 10-year period (2003-2012) at Hat Yai district, Songkhla province, southern Thailand as evaluated by Kendall's non-parametric correlation analysis

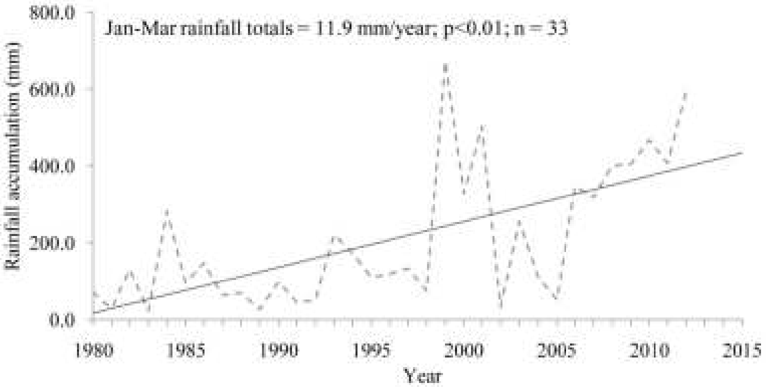

Fig. 6: Anomaly series and trend of rainfall accumulation in January-March during 33-year period (1980-2012) at Hat Yai station, Songkhla province, southern Thailand

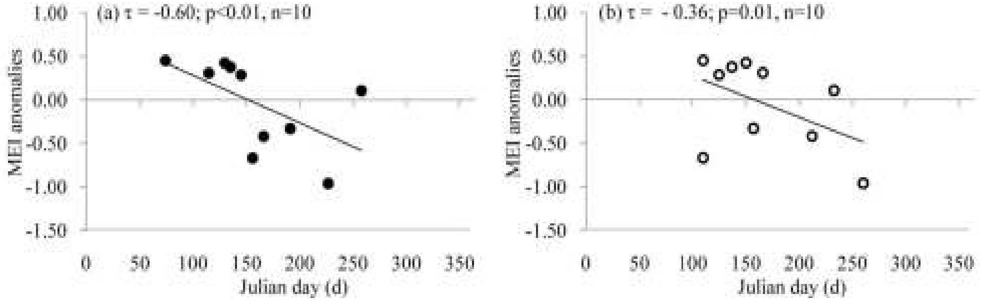

Fig. 7: Relationship between annual values of MEI and the flowering Julian dates of mangosteen, (a) longkong and (b) during 10-year period (2003-2012) at Hat Yai district, Songkhla province, southern Thailand as evaluated by Kendall's non-parametric correlation analysis

Figure 7 provides additional evidence of climate-related phenological change indicating that the flowering dates of mangosteen and longkong were, to some extent, association with the ENSO. There was tendency for advanced onset of flowering during the years of warm and dry phase of the ENSO (El Niño), while delayed flowering tended to occur during the years of cool and wet phase of the ENSO (La Niña). However, only the flowering dates of mangosteen significantly correlated negatively with annual values of MEI at the 95% confidence level. It implies that phenology of mangosteen respond to the ENSO events stronger than that of longkong.

DISCUSSION

We examined shifts in phenology of tropical fruits, it showed that during the last 30 years of the seasonal growth and phenological development of tropical fruits including mangosteen and longkong in the southern part of Thailand are correspondingly followed the average annual rainfall pattern. Normally, the flowering period takes place from March to April (Panapitukul and Chatupotel, 2001; Sdoodee and Chiarawipa, 2005). In addition to these results, the climatic causes for the observed trends in the beginning of flowering could now be presented. The different magnitudes and timing of rainfall and changes of water deficit period markedly influenced on changes of flowering phases. A change in the rainfall distribution affected the phenological changes of flowering of tropical fruits each year as reported by Qing *et al.* (2011), this indicated that the occurrence of dry periods during January-March and June-August might be required to stimulate flowering in the in-season and off-season, respectively. Sdoodee and Chiarawipa (2005) also reported that the drought period in southern Thailand usually occurred from February to March and a short dry period may occur during July and August. These results supported that mangosteen trees need a dry period to induce flowering (Nakasone and Paull, 1998; Chutinunthakun, 2001; Sdoodee and Chiarawipa, 2005; Salakpetch and Poonnachit, 2006), but it was found that summer rain caused no enough drying period to induce flowering (Sdoodee *et al*., 2010). This led to no flowering with leaf flushing instead (Apiratikorn *et al*., 2012).

Limjirakan and Limsakul (2012) also reported that despite the annual mean air temperature increased by 0.91°C over the past 38 years (0.024°C per annum), the trend in annual Epan has steadily declined on average by ~7.7 mm a-2 (i.e., mm per annum per annum) in Thailand. Recently, numerous available data from studies of plant phenology have indicated that phenological changes are mostly due to an increase in the number of days in the dry period (Menzel and Fabian, 1999). The impacts of water deficit in this study also imply that more phenological changes of the both species were related to the changes of drying periods, this evidence also was reported by Salakpetch and Poonnachit (2006). Besides, Ren *et al.* (2013) also reported that the distribution of precipitation also plays an important role in the soil water and plants interaction which will affect the plant growth and production. The analyzed trends in rainfall are in accordance with the results of Lee *et al.* (2007) who suggested that precipitation intensity and frequency play an important role in determining soil water movement in terms of infiltration and percolation processes. Thus, the magnitude, timing and translocation of precipitation are critical factors influencing the movement and availability of soil water and ecosystem dynamics (Stephenson, 1990; Ferrio *et al.*, 2005). Moreover, other long-term studies in the southern Thailand are needed to show different phenological responses to climate change for the disruption of flowering. Besides, the effects of rainfall distribution on alternate bearing of mangosteen were also reported that it might be due to summer rain (Sdoodee and Sakdiseata, 2013; Boonklong, 2005). It was evident that, annual rainfall change influenced on the phenological shift in both species. However, interactions remain unclear, it was found that flowering of mangosteen and longkong correlated with rainfall accumulation during January-March.

The results of this study confirm finding of other reports, concerning the influence of ENSO on the timing of flowering events. The most recent studies, an advanced timing of shifting plant phenology such as budding, leafing and flowering were found (Beaubien and Freeland, 2000; Kramer *et al.*, 2000; Chmielewski and RÖtzer, 2001). The result provides additional evidence of climate-related phenological change indicating that the flowering dates of mangosteen and longkong were extent, association with the ENSO. Importantly, both types of changes are likely to affect the entire phenology of a species. However, little research regarding the response of tropical fruits yield either the quantity or quality to climate change is reported. Therefore, the responses of tropical fruits to recent climate change are needed to be investigated further.

CONCLUSION

The change of seasonal growth and phenological development of tropical fruits including mangosteen and longkong in the southern part of Thailand are correspondingly followed the annual rainfall pattern, the evidence of increasing trends in averaged flowering dates. These results clearly indicate that mangosteen and longkong flowering phases have been remarkably delayed to shift to the second-half of the year instead of the first-half as usual. Climate variability during 33 years at Hat Yai district, Songkhla province was evident with increasing of rainfall, rainy days, maximum and minimum temperatures and relative humidity. It seems to be that a marked change in the rainfall distribution results in phenological changes of mangosteen and longkong. There was tendency for advanced onset of flowering during the years of warm and dry phase of the ENSO (El Niño), while delayed flowering tended to occur during the years of cool and wet phase of the ENSO (La Niña). It implies that more phenological changes of the both species were respond to ENSO events.

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