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Effects of Rainfall on Durian Productivity and Production Variability in Peninsular Malaysia

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ABSTRACT

Durian (*Durio zibethinus*) is a popular and economically valuable tropical fruit tree native to Southeast Asia. It is empirically known that weather conditions can affect spatio-temporal variations in durian production. However, few studies have investigated the influence of climatic and meteorological factors on durian production and variability. This study examined the spatio-temporal patterns of durian production in Peninsular Malaysia using published statistical data from different geographical scales (peninsular, state, and district). The effects of rainfall on durian production and yield were discussed. District-level durian production data for Peninsular Malaysia for six years (2015–2021, except 2019), published by the Malaysian Ministry of Agriculture and weather data from the World Weather Online were used for the analysis. Durian production and yield did not generally fluctuate across years at the peninsular scale but showed high variability among the years at the district level. There was a significant increase in rainfall in 2017, corresponding with a significantly lower yield. Therefore, these findings suggest that durian temporal productivity and production variability are influenced by extreme rainfall. Extreme rainfall could have reduced durian productivity by inhibiting flower bud induction and flowering, decreasing pollinator activity, and causing direct damage to the fruit and trees. However, the coefficient of variation was lower in districts with higher production, suggesting that artificial factors mitigated part of the variation in productivity because the effects of extreme weather could be mitigated by a well-managed plantation system in large farms.

Keywords: Extreme rainfall, phenology, production, tropical fruits, yield

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INTRODUCTION

Weather plays a significant role in tropical fruit production (Magdalita & Saludes, 2015; Ounlert & Sdoodee, 2015; Ramírez & Davenport, 2010). Due to climate change, many tropical regions have experienced longer and more intense heat waves over the past 40 years (Li, 2020). Moreover, there has been a notable trend in precipitation, with extreme precipitation events becoming more frequent and severe over the past 30 years (Ng et al., 2022). These climatic shifts render tropical ecosystems particularly vulnerable to climate changes, affecting the reproductive seasons of Southeast Asia's tropical rainforests (Numata et al., 2022). Therefore, it is crucial to identify the impact of weather on the productivity of tropical fruits.

Durian (*Durio zibethinus* L.) is a popular tropical fruit tree known as the “king of fruits." It is native to Southeast Asia and is mainly grown in Thailand, Malaysia, and Indonesia (Subhadrabandhu & Ketsa, 2001). It is an economically valuable fruit tree in Malaysia, accounting for 27.3% of total fruit production, 43.8% of total fruit area planted, and 78.0% of total fruit value (Department of Agriculture Malaysia, 2022). It is grown throughout Malaysia, with 150 registered varieties of durian (Department of Agriculture Malaysia, n.d.). Durian is harvested during two seasons in Peninsular Malaysia, from May to August and November to December (Lim & Luders, 1997). Geographic and temporal variations in durian production have been empirically demonstrated. For example, the variation between the maximum and minimum durian production in Peninsular Malaysia over 18 years (2000 to 2017) was shown to be about 2-fold (Ahmad et al., 2020). Durian production can be influenced by artificial factors such as irrigation, fertilization, pruning, artificial pollination, and pest and disease control, in addition to environmental factors, particularly climatic conditions, throughout the stages of flowering, fruiting, and harvesting (Ketsa et al., 2020; Salakpetch, 2005).

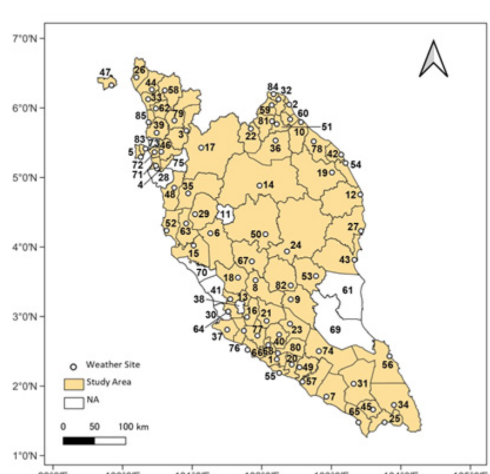
Dry periods are necessary for flower bud induction and flowering in durian, which influence productivity. The harvest season begins after the dry season in Peninsular Malaysia (Hoe & Palaniappan, 2013; Ketsa et al., 2020). Specifically, factors known to affect flower bud induction include at least 18 continuous days with daily precipitation of less than 1 mm (Zainab et al., 2002) and continuous dry periods of 7–14 days (Salakpetch, 2005). Weather conditions that affect flowering include a dry period of 10–14 days (Chandraparnik et al., 1992) and a dry season lasting 1–2 months (Yaacob & Subhadrabandhu, 1995). In addition, the wild durian species *Durio dulcis* and *Durio oxleyanus*, which are phylogenetically closely related to *D. zibethinus*, are known to synchronize with general flowering episodes observed in Southeast Asian rainforests at irregular intervals of several years (Fredriksson et al., 2006). Drought and low temperatures occurring on a seasonal scale of 2–3 months can explain the timing of large-scale synchronization of general flowering (Chen et al., 2018). Therefore, considering the close systematic relationship between durians and the two wild species (*D. dulcis* and *D. oxleyanus*) that exhibit synchronized flowering, the variability in durian productivity may be influenced by prolonged dryness and low temperatures. Previous studies have established that a dry period and low temperatures serve as triggers for flower bud induction and flowering. However, the extent to which weather conditions impact durian productivity is still unclear. In particular, tropical rainfall is intermittent temporally and spatially (Martin et al., 2016; Trenberth et al., 2017). Therefore, conducting analyses at a finer scale is ideal for understanding the spatiotemporal effects of rainfall on durian production.

This study examined the spatio-temporal patterns of durian production in Peninsular Malaysia using durian statistical data published by the Department of Agriculture. The effects of rainfall on durian production and on yield were examined. For the analysis, we used datasets from different geographic scales, namely Peninsular Malaysia, states, and districts. The spatio-temporal variation in annual durian production at the district level in Peninsular Malaysia was analyzed, and its relationship with rainfall in the same year was evaluated.

MATERIALS AND METHODS

Study Area

Peninsular Malaysia is located between 1°E and 7°E and between 99°W and 105°W. It includes 85 districts in 11 states (Figure 1). The region is characterized by various types of forest, including montane (oak) forests, hill dipterocarp forests, lowland dipterocarp



ID	District	State
1	Alor Gajah	Melaka
2	Bachok	Kelantan
3	Baling	Kedah
4	Bandar Baharu	Kedah
5	Barat Daya	Pulau Pinang
6	Batang Padang	Perak
7	Batu Pahat	Johor
8	Bentong	Pahang
9	Bera	Pahang
10	Besut	Terengganu
11	Cameron Highland	Pahang
12	Dungun	Terengganu
13	Gombak	Selangor
14	Gua Musang	Kelantan
15	Hilir Perak	Perak
16	Hulu Langat	Selangor
17	Hulu Perak	Perak
18	Hulu Selangor	Selangor
19	Hulu Terengganu	Terengganu
20	Jasin	Melaka
21	Jelebu	Negeri Sembilan
22	Jeli	Kelantan
23	Jempol	Negeri Sembilan
24	Jerantut	Pahang
25	Johor Bahru	Johor
26	Kangar	Perlis
27	Kemaman	Terengganu
28	Kerian	Perak
29	Kinta	Perak
30	Klang	Selangor
31	Kluang	Johor
32	Kota Bharu	Kelantan
33	Kota Setar	Kedah
34	Kota Tinggi	Johor
35	Kuala Kangsar	Perak
36	Kuala Krai	Kelantan
37	Kuala Langat	Selangor
38	Kuala Lumpur	Federal Territory
39	Kuala Muda	Kedah
40	Kuala Pilah	Negeri Sembilan
41	Kuala Selangor	Selangor

ID	District	State
42	Kuala Terengganu	Terengganu
43	Kuantan	Pahang
44	Kubang Pasu	Kedah
45	Kulai Jaya	Johor
46	Kulim	Kedah
47	Langkawi	Kedah
48	Larut & Matang	Perak
49	Ledang (Tangkak)	Johor
50	Lipis	Pahang
51	Machang	Kelantan
52	Manjung	Perak
53	Maran	Pahang
54	Marang	Terengganu
55	Melaka Tengah	Melaka
56	Mersing	Johor
57	Muar	Johor
58	Padang Terap	Kedah
59	Pasir Mas	Kelantan
60	Pasir Puteh	Kelantan
61	Pekan	Pahang
62	Pendang	Kedah
63	Perak Tengah	Perak
64	Petaling	Selangor
65	Pontian	Johor
66	Port Dickson	Negeri Sembilan
67	Raub	Pahang
68	Rembau	Negeri Sembilan
69	Rompin	Pahang
70	Sabak Bernam	Selangor
71	Seberang Perai Selatan	Pulau Pinang
72	Seberang Perai Tengah	Pulau Pinang
73	Seberang Perai Utara	Pulau Pinang
74	Segamat	Johor
75	Selama	Perak
76	Sepang	Selangor
77	Seremban	Negeri Sembilan
78	Setiu	Terengganu
79	Sik	Kedah
80	Tampin	Negeri Sembilan
81	Tanah Merah	Kelantan
82	Temerloh	Pahang
83	Timor Laut	Pulau Pinang
84	Tumpat	Kelantan
85	Yan	Kedah

Figure 1. Administrative division map of Peninsular Malaysia and the location of 75 districts and weather site used in this study

forests, mangroves, and peat swamps (Omar et al., 2017). In the Köppen world climate classification system, Peninsular Malaysia falls under a tropical rainforest climate (Af), characterized by high temperatures and humidity throughout the year. Temperatures range from 25°C–32°C and mean annual rainfall ranges from 2000 mm to 4000 mm (Suhaila & Jemain, 2007). Rainfall patterns in Peninsular Malaysia are affected by the north-east monsoon (NEM) from November to February and the south-west monsoon (SWM) from May to September (Mahmud et al., 2015). The timing of the wet and dry seasons varies according to geographical location. In eastern Peninsular Malaysia, the rainy season is during the northeast monsoon. In contrast, in the west, there are two rainy seasons per year: the inter-monsoon season from mid-March to May and October to November.

Durian Production Data

The genus *Durio* comprises approximately 30 species, but only *D. zibethinus* is cultivated for fruits on a large scale; therefore, this study focused on *D. zibethinus* (Lim, 1990). The annual production (mt) and planted area (ha) data for durian over six years (2015–2021, except for 2019 because the data was inaccessible) at three scales (Peninsular Malaysia, states, and districts) were obtained from the Department of Agriculture in Malaysia. This study used data from all 11 states and 75 districts in Peninsular Malaysia, excluding the ten districts with missing values: Cameron Highland, Pekan, Rompin, Kerian, Selama, Seberang Perai Utara, Klang, Kuala Selangor, Sabak Bernam, and Kuala Lumpur. According to the Department of Agriculture in Malaysia, the planted area covers all agricultural areas in Malaysia and was calculated using crop hectarage equivalent (CHE) methods. The CHE was obtained by dividing the number of trees planted on a particular lot by the recommended planting density per hectare of that particular crop. Production was estimated based on a crop production survey, potential yield, and farm records.

Weather Data

Daily rainfall (mm) and daily minimum temperature (°C) data were obtained from the World Weather Online (World Weather Online, 2023b) from 2015 to 2021, except for 2019, and the area covering 75 districts in 11 states, the same as the durian production data. Annual rainfall and minimum temperature data derived from daily rainfall and minimum temperature data were used in this study. World Weather Online provides historical weather forecast data for any geo-point by developing its own weather forecasting model using data from the World Meteorological Organization and other sources (World Weather Online, 2023a). Previous studies have also used these data (Gunthe et al., 2022; Ibekwe & Ukonu, 2019; Kamal et al., 2021). A previous study evaluated the accuracy of World Weather Online forecasts by comparing them with actual observations. It found a 70% correctness rate for rainfall forecasts for a one-day lead time in Kadoma, Zimbabwe (Terence et al., 2015).

Data Analysis

The yield (mt/ha) was calculated by dividing the production by the planted area. One-way analysis of variance (ANOVA) and Tukey's multiple comparison tests were performed to compare and clarify the temporal characteristics of each factor on durian production, yield, and rainfall for each year. The coefficients of variation (CV) of durian production and yield were calculated to evaluate the variability in the data relative to the mean at different spatial scales over six years at three scales: Peninsular Malaysia, state, and district. The six-year average for each district was taken as 100%, and the percentage difference from the average of each year's factors was calculated and mapped as an anomaly to visualize the spatial variation in production, yield, and rainfall. Spearman's rank correlation coefficients (r_s) between CV and 6-year mean production and between CV and 6-year mean yield at the district level were calculated to identify the characteristics of locations with high production variability.

Given that the harvest season in Peninsular Malaysia is from May to August and November to December and that it takes approximately three months for durian fruit to mature after flowering, the flowering periods would be from February to May and August to September (Lim & Luders, 1997; Subhadrabandhu & Ketsa, 2001). Since the flowering of tropical tree species is triggered by specific weather conditions a few weeks prior, it is likely that the weather conditions in the same year as the harvest influence durian flowering. Partial Spearman's rank correlation coefficients between production and rainfall and between yield and rainfall, excluding the influence of minimum temperature, were calculated to determine the spatial relationship between rainfall and production at the district level. All statistical analyses were performed using R ver. 4.2.2. All spatial analyses were conducted using a geographic information system QGIS 3.32.2.

RESULTS

Temporal Variability in Durian Production and Yield

Durian production and yield in Peninsular Malaysia from 2015 to 2021 (excluding 2019) displayed a relatively consistent trend, except for lower production and yield in 2017 (Figure 2a, 2b). One-way ANOVA showed no significant differences in the mean annual production from year to year ($p > 0.05$), whereas significant differences were observed in mean yield ($p < 0.05$). Tukey's multiple comparison tests showed that the mean yield was significantly lower in 2017 than in 2020 ($p < 0.05$) and 2021 ($p < 0.05$). Durian production and yield varied across different geographical scales and increased from the large (peninsular) to the small scale (district). The CV at the peninsular scale was 0.24 for production and 0.20 for yield. The mean CV was 0.40 for production, 0.32 for yield at the state level, 0.49 for production, and 0.41 for yield at the district level.

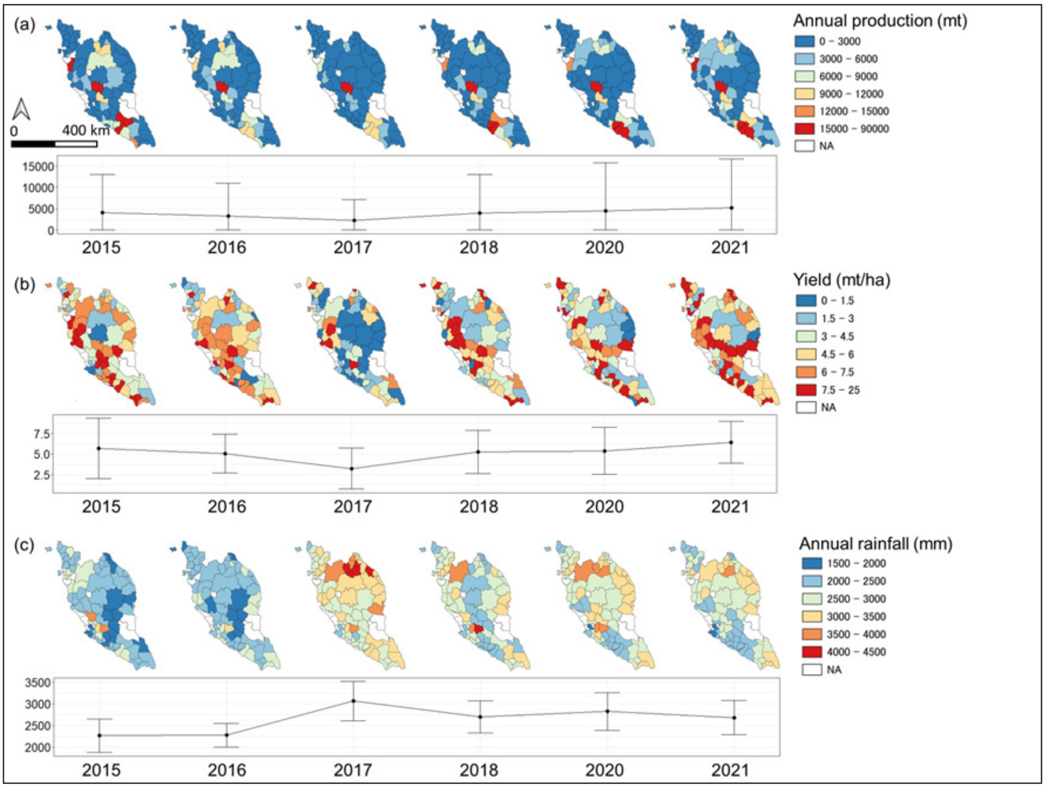


Figure 2. Geographical and temporal patterns of (a) annual production, (b) yield, and (c) annual rainfall at the district level in Peninsular Malaysia from 2015 to 2021, except for 2019. The graphs show the means (± SD)
Note. Legend of administrative divisions are shown in Figure 1

The annual production varied from 0.1 mt in Kuala Langat in 2015 to 85364.4 mt in Raub in 2021 (Figure 2a). Several districts (Raub, Ledang, Batu Pahat, and Muar) had high production; Raub had a large six-year mean production of 67977 mt, accounting for 23.3% of the total Peninsular Malaysia production. Production was consistently high in the southern part of the western coast of Peninsular Malaysia. The yield was highly uneven regionally, and the trends varied from year to year (Figure 2b). The yield ranged from 0.001 mt/ha in Kuala Langat in 2015 to 24.3 mt/ha in Jasin in 2015. It tended to be relatively high on the west coast of Peninsular Malaysia, particularly in 2015, 2020, and 2021, with relatively high yields in the southern part of the western coast of Peninsular Malaysia.

The results showed a significant negative correlation between the mean annual production and CV ($r_s = -0.36$, $p < 0.05$) and between the mean yield and CV ($r_s = -0.30$, $p < 0.05$). However, no significant relationship was observed between the annual production and yield.

Geographical Pattern of Temporal Variability in Durian Production and Yield Anomaly

The production and yield anomalies varied annually and geographically but showed low productivity throughout Peninsular Malaysia in 2017 (Figure 3a, 3b). The geographical pattern trends of production and yield in 2017 were similar, with declines, particularly in the central Peninsula. Specifically, in Peninsular Malaysia during that year, the mean annual production anomaly was -47.1%, with 92% of all districts showing a negative anomaly. Similarly, the mean yield anomaly for 2017 was -41.6% and 85.3% of all districts had a negative anomaly. From 2015 to 2016, the production and yield anomalies were higher in the central peninsula and lower in the coastal areas. Conversely, after 2018, especially in 2021, production anomalies were low in the central peninsula and high in the coastal areas.

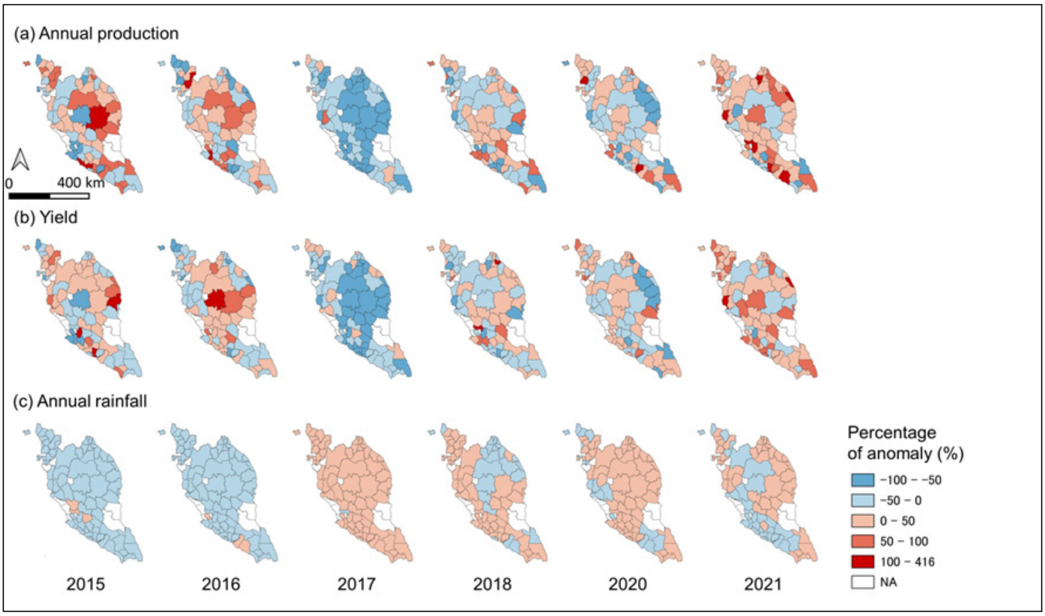


Figure 3. Spatial patterns of the percentage of anomalies for (a) annual production, (b) yield, and (c) annual rainfall at the district level in Peninsular Malaysia
Note. Legend of administrative divisions are shown in Figure 1

Temporal and Geographical Pattern of Annual Rainfall

The mean annual rainfall in 2017 was significantly higher ($p < 0.05$) than that in the other years in Peninsular Malaysia and was significantly lower in 2015 ($p < 0.05$) and 2016 ($p < 0.05$). The CV at the peninsular scale was 0.108, and the mean CV values were 0.114 and 0.130 on the state and district scales, respectively.

The annual rainfall ranged from 1531.8 mm in Kuala Pilah in 2016 to 4266.1 mm in Setiu in 2017 (mean 4266.1 mm). Rainfall was particularly low in the central Peninsula in 2015, 2016, and 2018 (Figure 2c). In 2018, 2020, and 2021, a trend of less rainfall in the southern part of the Peninsula's west coast and more rainfall in the northern part was observed.

Geographical Pattern of Temporal Variability in Rainfall Anomaly

Rainfall across Peninsular Malaysia was higher in 2017 and lower in 2015 and 2016 (Figure 3c). In 2017, rainfall anomalies were positive in all districts except for one, with a mean of 16.3%. Rainfall anomalies in 2015 and 2016 were negative in all but three districts, with mean values of 14.1% and 13.4%, respectively. The rainfall anomaly decreased in 2018 in the northern part of the east coast of Peninsular Malaysia and 2020 and 2021 on the western coast.

Spatial Relationship between Durian Production, Yield, and Rainfall

The partial Spearman's rank correlation results showed no significant correlations between production and rainfall or yield and rainfall (Table 1).

Table 1
Partial Spearman's rank correlation coefficients (r_s) between annual rainfall and annual production and between annual rainfall and yield

	Annual production		Yield	
Year	r_s	***p*-value**	r_s	***p*-value**
2015	0.07	0.53	0.09	0.43
2016	0.13	0.27	0.14	0.24
2017	0.10	0.42	0.03	0.81
2018	-0.05	0.70	0.03	0.81
2020	0.01	0.91	-0.05	0.67
2021	0.14	0.23	-0.09	0.43

DISCUSSION

This study found that higher-than-average rainfall may be the key to understanding the decline in durian productivity throughout Peninsular Malaysia. Durian production and yield were lower than average in 2017 when the level of rainfall throughout Peninsular Malaysia was significantly higher than average (Figure 2, 3). Therefore, it was concluded that durian temporal productivity and variability are influenced by extreme rainfall.

Extreme rainfall could have reduced durian productivity by suppressing durian flower bud induction and flowering, decreasing pollinator activity, and causing direct damage to fruits and trees. First, extreme rainfall reduces the dry period required for flower bud induction and flowering (Chandraparnik et al., 1992; Zainab et al., 2002). An insufficient dry period may have reduced production by reducing flower bud induction and flowering rate. Second, bats, which are important durian pollinators in Malaysia (Low et al., 2021), have been noted to decrease their foraging activity during wet weather periods (Mohd-Azlan et al., 2010). Durian is self-incompatible, and artificial cross-pollination is recommended for commercial production. However, natural pollination is also used because artificial pollination requires ladders at night to pollinate the flowers on high branches, which is dangerous and labor-intensive (Honsho et al., 2007).

Therefore, when rainfall is high in farms where natural pollination occurs, the reduced bat activity results in inadequate pollination, which decreases production. Third, extreme rainfall and flooding have been shown to directly damage durian fruits. A positive correlation was found between rainfall and durian fruit loss (Nicolas et al., 2019). Extreme rainfall and flooding caused by Typhoon Damrey were reported throughout Penang, Kedah, and Perak in November 2017 (NASA Applied Sciences, 2017). Because one of the two durian harvesting seasons in a year is November–December (Lim & Luders, 1997), direct damage to the fruit by extreme rainfall and flooding may have contributed to the decline in production. The results suggest a potential increase in years with decreased durian production due to increased precipitation associated with abnormal weather patterns. Projections indicate an anticipated average precipitation increase of 10%–20% throughout the 21st century in the Indochina Peninsula (Tangang et al., 2020). Therefore, addressing extreme rainfall is crucial when considering variations in durian production.

Although a temporal correlation between productivity and extreme rainfall was observed, no spatial correlation was found (Table 1). This result suggests that changes in rainfall within the same location can affect productivity; however, the amount of rainfall in that specific location compared to other locations does not impact productivity. Therefore, the spatial distribution of productivity may be influenced by meteorological factors other than rainfall or human interventions, indicating the need for further research.

Several points should be noted regarding the durian statistical data used in this study. First, the statistical data were annual data with two harvest seasons combined in some areas, making it difficult to identify the timing of weather conditions that affect each harvest season. Second, because the statistical data was not variety-specific, it was impossible to discuss the differences in productivity and environmental responses among the varieties. Additionally, the differences in CVs at different scales may have occurred because of the weak spatial correlation between production and yield, which may have offset the observed range of variability in each district, resulting in a smaller assessment of the variability range at the state and peninsular levels. Although these limitations are unlikely to affect the conclusions of this study, more detailed analyses at wider spatiotemporal scales and variety-specific data would provide a deeper understanding of the mechanisms by which extreme rainfall affects durian production.

The results also showed that highly productive areas exhibit low variability. In general, districts with high production have large farms, possibly for export, and may, therefore, have strict production management practices, such as fertilization and pest/vermin management (Datepumee et al., 2019; Thongkaew et al., 2021). Artificial pollination (Honsho et al., 2004) and soil moisture monitoring (Ramli et al., 2022) can reduce the negative effects of heavy rainfall. Therefore, extreme rainfall effects can be mitigated on large farms using a well-managed plantation system.

CONCLUSION

This study used durian statistical data to examine the spatio-temporal patterns of durian production in Peninsular Malaysia and discussed how rainfall affects durian production and yield. The results suggested that production and yield decreased in 2017 because of high annual rainfall. Therefore, it was concluded that extreme rainfall could significantly influence durian temporal productivity and variability. Two possible reasons exist for the weak correlation between durian productivity and rainfall. First, production and harvest control may partly mitigate the variations in productivity. Such artificial factors can obscure the spatial and temporal relationships between rainfall and durian productivity. In addition, the statistical data used in this study were not data by harvest period or variety, making it difficult to discuss the relationship between durian production and rainfall in terms of differences in productivity and environmental responses among varieties and to identify the timing of climatic conditions. It is necessary to consider the time lag in production data and investigate how extreme rainfall affects durian's reproductive processes to understand the mechanism by which extreme rainfall affects durian production.

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