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Impact of Seasonal Weather Variations on Physical Attributes of Robusta Coffee Beans

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ABSTRACT

Background: Robusta coffee is a type of cultivated agricultural commodity. It is grown to produce high-quality coffee. The weather conditions have a significant impact on the characteristics of green coffee beans, such as their aroma and taste. As a result, fluctuations in weather conditions can affect the quality of the final product.

Methods: This study assessed Robusta coffee beans′physical properties and defects in southern Thailand. The characteristics of green coffee beans and the weather variations of the southern peninsula were observed.

Result: It was found that significantly different proportions of normal, pea berry and defective coffee beans were found across geographical regions. In areas with high rainy days and total rainfall, full black disorder had a higher incidence (16.46%) of defective coffee beans. Additionally, the geometric mean diameter (GMD) and surface area of green coffee beans had a significant positive correlation with minimum temperature (Tmin) after the 6-to 9-month period of fruit setting. This study indicates that recent weather variations have had a significant impact on the characteristics and quality of Robusta green beans. The improvement of green coffee bean practices to achieve high-quality Robusta beans in response to pre-harvest weather conditions should be further investigated.

Key words: Coffee agroecology, Defect, Fine Robusta, Green bean, Weather variation.

INTRODUCTION

The quality of coffee beans is influenced by various factors, including geographic location, cultivation conditions and bean characteristics (Worku *et al.,* 2018). Geographic location significantly impacts coffee bean quality, with temperature and sunlight affecting flavor and aroma (Tolessa *et al.,* 2017). Robusta coffee is a significant agricultural commodity in multiple regions across the globe and is extensively cultivated in tropical areas (Ababu and Getahun, 2021). In addition, Robusta coffee is a botanical entity that thrives exceptionally well in the southern regions of Thailand, constituting approximately 51% of the nation's entire coffee output (Office of Agricultural Economics, 2022). The quality of Robusta coffee is influenced by various environmental factors, including temperature, humidity and rainfall, thereby impacting the occurrence of defects in unripen coffee beans (Ahmed *et al.,* 2021). Moreover, the defect identified in the beans has a discernible adverse effect on the aroma and taste of the coffee (Specialty Coffee Association, 2018).

Farmers in the southern region of Thailand engage in the cultivation of Robusta coffee, which is highly favored in areas with mixed orchards and rubber plantations (Chiarawipa and Sirikantayakul, 2015). The growing conditions for coffee beans can range from open to shaded environments, with varying intensities (Chiarawipa *et al.,* 2021). Although Robusta coffee can grow in a wide range of climates, the coffee plants might produce smaller beans with lower-quality seeds when inadequate water is applied during cherry development (DaMatta *et al.,* 2018). Furthermore, pre-harvest weather conditions significantly impact the physical characteristics of coffee beans (Bunya-atichart *et al.,* 2018). Both altitude and climatic variations have a direct impact on the quality of coffee beans produced (Cassamo *et al.,* 2022). The physical attributes of coffee beans exhibit variability based on the environmental factors in the planting area, including topography, climate, soil fertility (Wintgens, 2012; Hareesh and Jayarama, 2024) and pest population in the coffee plantation (Rimbing *et al*., 2023).

To ensure the quality of the coffee beans, it is important to consider the suitability of the planting site's conditions

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during the pre-harvest stage, as well as the management of the harvesting and post-harvest periods. The main aim of this particular study was to assess the physical characteristics and defect properties of Robusta coffee beans in the Southern Thailand region, while also evaluating the variations in growing seasonal weather.

MATERIALS AND METHODS

The study was conducted at four major Robusta coffee plantations in four provinces, in Southern Thailand: Ranong-Kra Buri (RN-KR) (altitude 82 m), Chumphon-Tha Sae (CP-TS) (altitude 483 m), Surat Thani-Phanom (SR-PN) (altitude 143 m) and Krabi-Plai Phraya (KB-PY) (altitude 135 m). In these regions, coffee plantations have been established on a large scale. The arrangements varied according to the geographical locations, which are rainfed orchard systems. The dry process of Robusta coffee beans was used to retain the natural flavors. After the collection of the cherries, they were subjected to solar drying. To conduct the dry process processing, a set of coffee cherries was selected at random and positioned within a pristine and sunny area for 3-4 weeks until reaching a humidity level of 9-12%. When the coffee cherries were dry, they could then be put into a huller machine to remove the outer husk. The beans were also laid out in the sun for a few days to ensure that the moisture content was reduced. To evaluate the characteristics of beans, it was then followed by sorting the beans according to weight, color and physical properties.

The categorization of coffee beans comprises three distinct types: regular beans, pea berry and defect. For analysis, three separate samples, each weighing 350 g, were assessed at various locations using an analytical balance (model ES-1200HA, Zepper scales LTD, China). Subsequently, the proportions of each coffee bean type were recorded.

After that, the defective beans were classified according to their disorders as described by the Uganda Coffee Development Authority (UCDA) standards. It has also implemented a method for sorting and verifying the integrity of the beans to produce quality coffee beans (Coffee Quality Institute, 2018).

All coffee beans were classified according to the severity that affects coffee quality into 6 primary defects: Full black, full sour, cherry/pod, fungus damage, foreign matter and severe insect damage and 11 secondary defects: Partial black, partial sour, parchment, floater, immature/unripe, withered, shell, broken/chipped/cut, hull/husk, slight insect damage and chalky (Coffee Quality Institute, 2018) to compare the degree of abnormality of coffee beans at each location. Each defective bean of Robusta coffee was then weighed to calculate the respective percentages.

The physical properties of Robusta coffee beans were assessed at each location by randomly selecting 1 kg per location and conducting three replicates of 100 seeds. To determine the width (a), length (b) and thickness (c) of the coffee beans, a digital vernier caliper was used. The equations used to calculate the physical characteristics were adapted from Mohsenin method (Mohsenin, 1971; Kattalee and Inprasit, 2012), specifically the following equations:

$$\text{Geometric mean diameter (GMD) (cm)} = (a*b*c)^{1/3} \quad ...(1)$$

$$\text{Sphericity (\%)} = \frac{GMD}{b} \quad ...(2)$$

$$\text{Volume (cm}^3\text{)} = \frac{[(\pi*a*c)*b^2)]}{[6*(2b-(a*c)^{1/2})]} \quad ...(3)$$

$$\text{Surface area (cm}^2\text{)} = \pi*(GMD)^2 \quad ...(4)$$

Bulk density (ρ) (g/cm^3); the volume of the cylinder (volume; v) is then filled with coffee beans and weighing the mass of coffee beans (mass; m)

$$\frac{m}{v} \quad ...(5)$$

To analyze the color of Robusta coffee beans, 30 beans from 350 g were randomly sampled per area and assessed using a colorimeter (CR-400 Chroma meter, Minolta, Japan). The CIELAB system (L*, a* and b* values) was recorded and compared to determine the average color values.

Monthly datasets of air temperature, including maximum temperature (Tmax) and minimum temperature (Tmin), total rainfall and relative humidity (RH) were observed during 2019 to 2020. The meteorological data were collected from agricultural meteorological stations located in four provinces. The relationship between monthly weather variables (at the 3rd, 6th, 9th and 12th months after fruit setting periods) and physical properties of green beans from those stations were analyzed using linear and non-linear regressions. Furthermore, the average altitude above sea level was recorded, encompassing the diverse locations of the coffee orchards.

To analyze the variance of the data, a completely randomized design was used and ANOVA (Analysis of Variance) was conducted. The mean was compared using the Duncan′s New Multiple Range Test (DMRT) method at a 95% confidence level, which was carried out using the R program. Regression analysis was utilized to assess the geographical and weather variables that exert the most significant influence on the physical properties and size of coffee beans ($r^2 \geq 0.65$).

RESULT AND DISCUSSION

Defect classification of robusta coffee beans

In KB-PY, normal beans were the most prevalent, accounting for 74.71% of the samples, showing a statistically significant difference compared to coffee beans from RN-KR, where normal beans were least common at 58.25%. On the other hand, CP-TS had the highest percentage of pea berry beans at 18.62%, which was similar to RN-KR’s 17.44%, but significantly different from SR-PN

(16.15%) and KB-PY (13.44%). Notably, RN-KR (24.31%) had the highest occurrence of total defects, which differed significantly from the other locations. The lowest total defect was found in KB-PY (11.85%) (Table 1).

In terms of major defects (category 1) and minor defects (category 2) observed in Robusta coffee beans, RN-KR exhibited the highest occurrence of primary defects at 16.82%, while KB-PY had the lowest percentage of secondary and minor defects at 7.80% and 4.60%, respectively. When considering the total of defects, RN-KR had the highest percentage of total defects at 24.63%, whereas KB-PY had the lowest percentage of total defects at 12.40%. The primary defect that stood out the most was full black in RN-KR, accounting for 16.46%. As for minor defects, slight insect damage was the most prominent across all locations, ranging from 2.10% to 4.38%. However, no instances of parchment, floater, or shell disorders were observed in any of the locations (Table 2).

The full black defect in coffee beans is a type of category 2 defect according to the Specialty Coffee Association (SCA) standards (Specialty Coffee Association, 2018). This defect is characterized by blackened, darkened, or burnt beans that can occur as a result of over fermentation or over drying of the beans during processing. Additionally, this defect can be attributed to the occurrence of fungal infections or damage caused by insects on the beans. To identify full black beans, one can observe their dark and lustrous appearance, which can adversely affect the coffee's flavor profile by imparting a burnt or bitter taste (Gonzalez-Sanchez *et al.,* 2024). Meanwhile, the most common minor defects in green beans are slight insect damage, broken or chipped flesh and cuts that damage the seeds. These defects can occur during the post-harvest process, such as during harvesting, transportation, or storage. Farmers should sort the coffee beans to identify and remove these defects, as they can affect the quality, including its flavor and aroma.

Approximately 10% to 30% of coffee defects emerge throughout harvesting. Additionally, coffee production is subject to the influence of climate change, whereby variations in rainfall patterns and occurrences of extreme weather events directly affect the yield and quality of coffee (Legesse, 2022; Rimbing *et al.,* 2023). Similarly, this study

Table 1: Classification of percentage of normal bean, pea berry and defect.

Coffee beans	Normal bean (%)	Pea berry (%)	Defect (%)
RN-KR	58.25±1.84c	17.44±1.17b	24.31±2.20a
CP-TS	65.56±4.05b	18.62±1.29a	15.82±3.53c
SR-PN	64.97±1.32b	16.15±1.33c	18.88±1.94b
KB-PY	74.71±2.00a	13.44±0.98d	11.85±2.05d

Mean (±S.D.) in the same column with different letters are significantly different at P≤0.05 by DMRT.

Table 2: Defects of robusta coffee beans in southern Thailand as UCDA standard.

Defect category	Green beans			
	RN-KR	CP-TS	SR-PN	KB-PY
Category 1:				
Full black	16.46±2.05a	9.23±1.80bc	10.86±2.12b	7.74±1.32c
Full sour	0.24±0.14	0.00	0.16±0.13	0.00
Cherry/pod	0.13±0.07b	0.09±0.04b	0.51±0.19a	0.00
Fungus damage	0.13±0.11	0.00	0.00	0.00
Foreign matter	0.09±0.03	0.09±0.05	0.10±0.05	0.08±0.08
Severe insect damage	0.19b	0.30±0.14b	0.75±0.23a	0.11±0.05b
Total category 1 (%)	16.82	9.62	12.19	7.80
Category 2:				
Partial black	0.99±0.53b	1.08±0.57ab	1.48±0.47a	0.98±0.41b
Partial sour	0.00	0.00	0.08±0.09	0.05
Parchment	0.00	0.00	0.00	0.00
Floater	0.00	0.00	0.00	0.00
Immature/unripe	0.00	0.00	0.16±0.09b	0.55a
Withered	0.50±0.04	0.00	0.20±0.08	0.36±0.39
Shell	0.00	0.00	0.00	0.00
Broken/chipped/cut	4.64±0.67a	3.25±0.39b	1.27±0.35c	0.42±0.16d
Hull/husk	0.08±0.03	0.33±0.09	0.10±0.05	0.02±0.02
Slight Insect damage	2.10±1.78d	3.63±0.59b	4.38±1.07a	2.80±0.05c
Chalky	0.00	0.08±0.60	0.00	0.00
Total category 2 (%)	7.81	7.94	7.26	4.60
Total defect (%)	24.63	17.56	19.45	12.40

Means±S.D. in the same column with different letters are significantly different at P≤0.05 by DMRT.

found that the impacts of elevated total rainfall levels resulted in a rise in the prevalence of full black beans in the RN-KR location. Moreover, the study revealed that rainfall variation was associated with discolored beans having a higher blue-green color (Table 3). A large number of the main defects found, in full black, were caused by fermentation in processing or microbial infection from dropped or overripe seeds. This is most prominent in the RN-KR samples. To avoid these defects, farmers should harvest the cherries at the appropriate maturity and follow the climatic conditions (Worku *et al.,* 2018). Although farmers cannot avoid harvesting the coffee cherries during periods of heavy rainfall, it is imperative that they subsequently desiccate the cherries in an area that is sheltered and facilitates air circulation.

This study has provided evidence to suggest that climatic conditions substantially influence the imperfection of Robusta green coffee beans (Bunn *et al.,* 2015). It has been ascertained that an excess of rainfall is correlated with a heightened manifestation of defect attributes in the province of RN. To mitigate such losses, agriculturalists

Table 3: Color shades of Robusta coffee beans using the CIELAB system (L*, a*, b*).

Locations	Color parameters		
	L*	a*	b*
RN-KR	53.78±5.68b	3.86±2.02d	20.31±5.41b
CP-TS	54.75±5.63b	6.23±2.84b	22.16±3.10a
SR-PN	50.88±6.05c	7.42±2.05a	22.90±3.55a
KB-PY	58.92±5.18a	5.03±2.08c	22.08±2.23a

Means±S.D. in the same column with different letters are significantly different at P≤0.05 by DMRT.

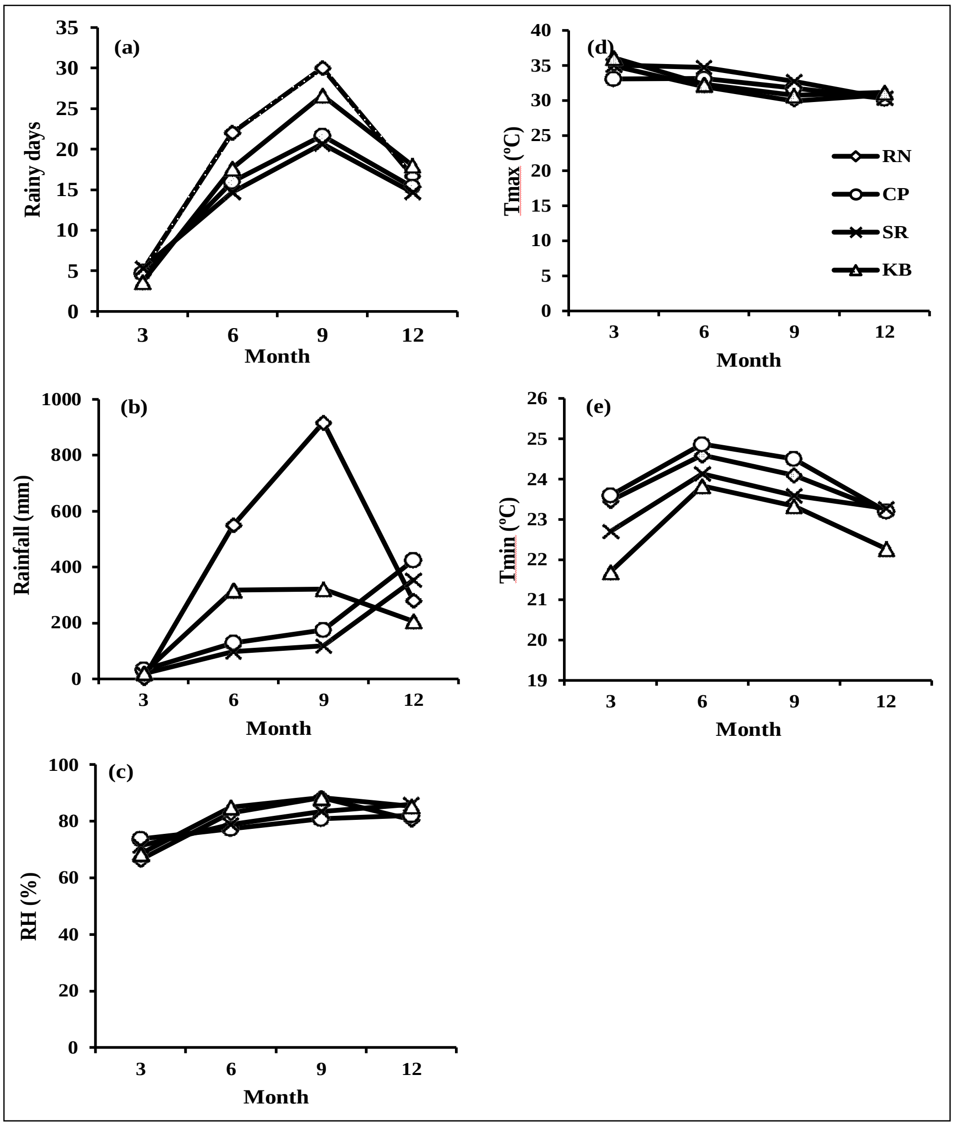

Fig 1: Variations in the rainy days (a), rainfall (b), relative humidity (RH) (c), maximum temperature (Tmax) (d) and minimum temperature (Tmin) (e) at the 3rd, 6th, 9th and 12th months after fruit setting periods in four provinces, Southern Thailand.

ought to implement measures to prevent the occurrence of minor imperfections. These measures encompass sound farming techniques, such as implementing appropriate harvesting and storage practices.

Weather variations on characteristics of coffee bean

During the growing season (at the 3^{rd}, 6^{th}, 9^{th} and 12^{th} month after fruit setting periods), plentiful rainfall was found in RN province (1,649.46 to 2,750.82 mm), although rainy days are high during 6^{th} and 9^{th} month (22 to 30 days) (Fig 1). The average Tmin was highest in CP province (23.20 to 24.87°C) after decreasing from the 6^{th} to 12^{th} month. Meanwhile, Tmax was similar highest in SR and KB provinces (30.37 to 36.10°C) during the growing season. All locations, RH was slightly increased during the 9^{th} to 12^{th} month, with an average RH of 77.33 to 84.93%, 80.87 to 88.33% and 80.47 to 86.00%, respectively.

KB-PY coffee beans exhibited the highest L* with a value of 58.92, which was statistically distinct from the other coffee beans. In terms of a* testing, SR-PN displayed the highest value at 7.42, which was significantly different from RN-KR coffee beans that had the lowest value at 3.86. Regarding the b* value, coffee beans from RN-KR recorded the lowest value at 20.31, while coffee beans from other locations fell within a similar range of 22.08-22.90 (Table 3).

When considering the physical properties (geometric mean diameter, sphericity, volume and surface area) of coffee bean, CP-TS exhibited the highest values among all parameters (0.628 cm, 75.317%, 0.266 cm^3 and 1.247 cm^2, respectively), whereas KB-PY showed the lowest values (0.591 cm, 72.543%, 0.177 cm^3 and 1.107 cm^2, respectively). In terms of bulk density, SR-PN had the highest value at 3.090 g/cm^3, which was statistically significantly different from RN-KR coffee beans (2.963 g/cm^3) (Table 4).

Table 5 shows the overall regression analysis. The results showed that total rainfall, RH, Tmax and Tmin during the 9-month period after fruit setting had a positive effect

Table 4: Physical properties of Robusta green coffee beans in Southern Thailand.

Coffee beans	Physical properties				
	Geometric mean diameter (cm)	Sphericity (%)	Volume (cm^3)	Surface area (cm^2)	Bulk density (g/cm^3)
RN-KR	0.621±0.057ab	73.514±5.235b	0.204±0.110b	1.222±0.215ab	2.963±0.001d
CP-TS	0.628±0.048a	75.317±5.909a	0.266±0.224a	1.247±0.198a	2.995±0.002c
SR-PN	0.060±0.070bc	73.681±5.016b	0.208±0.095b	1.169±0.269bc	3.090±0.003a
KB-PY	0.591±4.197c	72.543±4.197b	0.177±0.064b	1.107±0.209c	3.030±0.004b

Mean±S.D. in the same column with different letters are significantly different at P≤0.05 by DMRT.

Table 5: The relationship between weather variations (9^{th} month after fruit setting) and physical properties of Robusta green coffee beans.

Weather	Physical properties	Equations	Coefficient of determination (r^2)
Rainfall	GMD	y= 0.00005× + 0.6072	0.059
	Sphericity	y= -0.0009× + 74.106	0.081
	Volume	y= 0.005× + 0.2257	0.090
	Surface area	y= 0.0005× + 1.1708	0.056
	Bulk density	y= -0.0001× + 3.0615	0.554
RH	GMD	y= -0.0023× + 0.811	0.273
	Sphericity	y= -0.2695× + 96.733	0.759
	Volume	y= -0.0087× + 0.9574	0.749
	Surface area	y= -0.0089× + 1.9441	0.281
	Bulk density	y= -0.004× + 3.3577	0.074
Tmax	GMD	y= -0.0004× + 0.6238	0.001
	Sphericity	y= 0.3703× + 62.171	0.154
	Volume	y= 0.0114× - 0.1425	0.137
	Surface area	y= -0.0004× + 1.1978	0.001
	Bulk density	y= 0.0360× + 1.8918	0.656
Tmin	GMD	y= 0.0313× - 0.1366	0.954*
	Sphericity	y= 1.9731× + 26.639	0.794
	Volume	y= 0.0642× - 1.3188	0.791
	Surface area	y= 0.1163× - 1.5912	0.938*
	Bulk density	y= -0.065x + 4.5709	0.388

* =Significantly different at P≤0.05.

on physical properties. Importantly, the relationship between Tmin with GMD (r^2= 0.954) and Tmin with surface area (r^2=0.938) was found to be statistically significant ($p \leq 0.05$).

Studies have also shown that environmental conditions can affect the characteristics of Robusta green beans. The environmental factor of rainfall can affect the bulk density of coffee beans, as excessive rainfall during the ripening stage can lead to increased moisture content and lower bulk density (Kath *et al*., 2021). This can result in lower quality coffee beans and potential difficulties in the roasting process. The air temperature is an important factor that affects the physical properties of coffee beans. An increase in air temperature can result in a decrease in coffee bean volume, diameter, surface area and sphericity. This reduction in physical properties can have negative impacts on coffee quality and processing (Halagarda and Obrok, 2023). Moreover, high temperatures can cause defects such as discoloration, surface blemishes and cracked beans, reducing the quality of the beans (Kath *et al*., 2021; Gonzalez-Sanchez *et al.,* 2024).

The physical properties of the coffee beans can also affect the quality of the coffee. This was related to the geometric mean diameter (GMD) and volume of the beans. The annual total rainfall in the KB-PY region is only 1,474 mm, which is significantly lower than the annual total rainfall in the coffee-growing regions of RN-KR and CP-TS, which receive an average of 3,828.7-1,764.5 mm of rain per year (Fig 1). The difference in rainfall is likely a contributing factor to the size and quality of the coffee beans in the KB-PY region (Table 4). Excessive rainfall can lead to a decrease in the body and sweetness of a roasted bean. Additionally, orchard management practices, such as pruning, fertilization (Leite *et al.,* 2015; Hareesh and Jayarama, 2024) and irrigation (Lina *et al.,* 2022), have been found to affect the flavor and yield of unprocessed coffee beans, resulting in increased concentrations of aromatic compounds, higher levels of caffeine and improved yields (Hagos *et al.,* 2018; Hameed *et al.,* 2018).

CONCLUSION

The physical characteristics and defect prevalence of coffee beans demonstrably vary according to the elevation of the growing region and the prevailing weather conditions during the cherry development, encompassing factors such as rainfall, temperature and relative humidity. These environmental elements exert a significant influence on coffee bean characteristics and, consequently, the overall quality of the final coffee product. Notably, this dependence on environmental conditions presents a unique criterion for coffee quality assessment, potentially adding value to the offerings of individual coffee farmers.

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Conflict of interest

All authors declare that there is no conflict of interest.

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