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Research article

Ecological Factors Governing the Persistence of Khlong-Saeng Durian: Implications for Conservation

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Abstract: The Khlong-Saeng durian (*Durio* spp.) of Surat Thani is undergoing a decline, leading to an investigation of environmental factors affecting its longevity. This study examined the relationship between soil properties and the age of native durian trees in Ban Khao Thep Phithak. Using geographic indices, correlation analysis, and preliminary phytochemical screening of peel waste, we identified factors influencing tree lifespan. Durian trees occurred in areas with temperatures of 26–31°C and relative humidity between 58.87% and 87.37%. A strong positive correlation was found between tree age and the dependent variable ($r = 0.75$, $p < 0.05$). All age groups were associated with silty soils, with significant variation in texture ($p < 0.001$, $F(10, 22) = 42.96$). Soil chemistry also differed significantly with tree age. Key parameters included soil pH ($p < 0.001$), organic matter ($p < 0.001$), nitrogen ($p < 0.001$), potassium ($p < 0.001$), phosphorus ($p < 0.001$), calcium ($p < 0.001$), and sodium ($p < 0.001$). Phytochemical screening showed antioxidant activity in the peels of trees over 50 years old, suggesting an age-related accumulation of bioactive compounds. Together, these results provide the first evidence linking soil nutrients and phytochemical markers to the longevity of Khlong-Saeng durian. The findings highlight the importance of maintaining optimal soil conditions and conserving high-elevation habitats to safeguard this unique genetic resource. Such knowledge is essential for sustainable cultivation strategies and long-term conservation of native durian in Southern Thailand.

Keywords: *Durio* spp.; environmental factors; native durian conservation; phytochemical screening; sustainable utilization

1. Introduction

Southern Thailand, a region characterized by its significant biodiversity and distinct tropical ecosystems, serves as a vital reservoir for unique plant genetic resources. Within this ecologically important area, Surat Thani Province is notable for being the native habitat of several endemic fruit varieties, among which the Khlong-Saeng durian (*Durio* sp.) holds a special place [1]. This specific local landrace is highly regarded by local communities for its exceptionally fragrant aroma and uniquely delicious flavor profile, representing a valuable component of the region's agricultural heritage and biodiversity [1]. Its distinctiveness underscores the importance of understanding and preserving such locally adapted plant varieties [2]. However, the continued existence of the Khlong-Saeng durian is facing considerable pressure. Historical land management practices, including extensive timber harvesting, have altered the landscape. More recently, the expansion of commercial monocultures, particularly oil palm and rubber plantations, has led to significant habitat fragmentation and loss for native species. Compounded by potentially insufficient public awareness and promotion ("poor public relations"), these pressures have resulted in a noticeable decline in the Khlong-Saeng durian population. This decline signifies not only the potential loss of a unique fruit but also contributes to genetic erosion, diminishing the overall biodiversity and resilience of the local ecosystem [3].

Conserving locally adapted landraces, such as the Khlong-Saeng durian, is of paramount importance. These varieties often possess unique genetic traits conferring resilience to local pests, diseases, and environmental conditions, representing an invaluable resource for future crop improvement and adaptation strategies, especially in the face of climate change [4]. Furthermore, safeguarding such varieties contributes to maintaining the rich tapestry of global biodiversity and preserves elements of local cultural identity intrinsically linked to native flora. The *in situ* conservation (protection within their natural habitat) of these genetic resources is therefore a critical environmental and societal goal [5]. Understanding the factors that enable long-term survival, or longevity, is fundamental to effective plant conservation. Generally, plant longevity is influenced by a complex interplay of genetic predispositions and environmental factors. Critical environmental variables often include soil characteristics (such as nutrient availability, like potassium, and pH), water regimes, elevation, topography, and prevailing climatic conditions. Recent studies have demonstrated that optimal durian persistence is often associated with moderate elevations (200–400 m), well-drained soils with balanced macronutrient profiles, and relative humidity levels that support consistent flowering and fruiting cycles [6]. Research in tropical fruit tree ecology has further emphasized that soil organic matter content and seasonal moisture stability can significantly extend tree lifespan by promoting root health and nutrient cycling [7]. Studies in diverse ecosystems, like the environmentally determined flora distributions in the Canary Islands or the observed links between elevation, persistence, and longevity in Mediterranean conifers, illustrate how specific environmental niches support long-lived plant populations. However, a significant knowledge gap remains concerning the specific drivers of longevity for tropical tree species, particularly those like the Khlong-Saeng durian, which are not widespread commercial cultivars. Factors governing the persistence of these unique tropical trees are largely undocumented. The primary aim is to identify and analyze the key environmental variables systematically – encompassing both physical site attributes (e.g., elevation, slope, aspect) and soil chemical properties – that exert a significant influence on the longevity and persistence of native Khlong-Saeng durian trees within their natural habitat in the Ban Khao Thep Phithak area of Surat Thani. Therefore, a secondary objective involves the preliminary phytochemical screening of Khlong-Saeng durian peel samples. This information is crucial for exploring potential avenues for the sustainable utilization of this peel waste, thereby fostering awareness of its potential value and local applications. Ultimately, this investigation seeks to establish a much-needed foundational knowledge base. Highlights of this research include (1) identifying the environmental and soil chemical factors most strongly correlated with the persistence of native durian trees, (2) providing the first phytochemical profile of Khlong-Saeng durian peel, and (3) linking ecological conservation strategies with potential economic benefits from agricultural byproduct utilization. The findings are expected to provide direct, evidence-based insights to guide targeted conservation strategies for the threatened Khlong-Saeng durian, focusing on preserving the environmental conditions conducive to its long-term survival. Simultaneously, by characterizing the peel's phytochemistry, the study aims to contribute to more holistic and sustainable management practices within the region, promoting the responsible use of resources and potentially adding value to agricultural byproducts. This research endeavors to bridge critical gaps in tropical plant ecology, conservation science, and sustainable resource management.

2. Materials and Methods

2.1 Study area

The research was conducted in Ban Khao Thep Phithak, located within the Khao Phang sub-district of Ban Ta Khun district, Surat Thani Province. This area is characterized by a valley-like formation, marked as No.1, 2, and 3, and intersects with the reservoir of Rajjaprabha Dam. It features a drainage system connecting the surrounding regions. Access to this area is limited to a single entrance and exit, with coordinates ranging from latitude 8.940 to 8.954 and longitude from 98.812 to 98.826 (Figure 1).

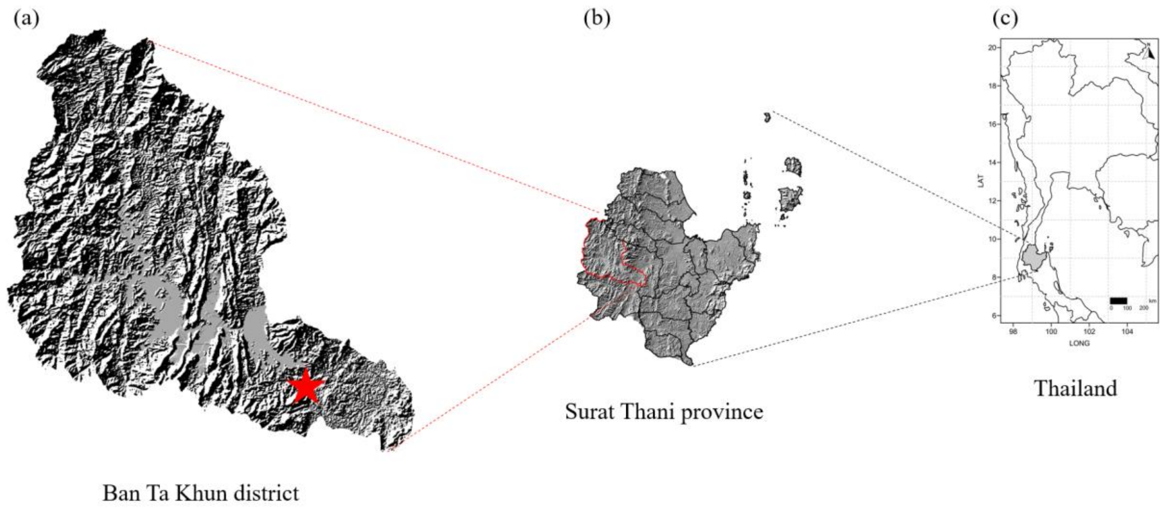

Figure 1. The study area, the red star represented the working area, the Ban Khao Thep Phithak in the Khao Phang sub-district, Ban Ta Khun district (a), in Surat Thani province (b), in the southern part of Thailand (c).

2.2 Field sampling

Data collection took place between July and September 2024. The sample included durian trees situated in Khlong Saeng (KS) and encompassed essential information for academic investigation. Measurements and records were obtained for various parameters, including temperature, soil pH, soil moisture, air humidity, elevation, tree circumference, and canopy dimensions. Additionally, fruit samples were gathered in August 2024, coinciding with the fruiting season.

2.3 Durian peel sampling

To obtain crude extracts from Durian peels, the initial step involved chopping the samples, followed by drying them at 50°C for 24 hours. Subsequently, the dried samples were subjected to methanol extraction at a ratio of 10 g of the dry sample per 100 mL of methanol, utilizing reflux extraction over a 2-hour duration. The resultant solution was then filtered through filter paper to isolate the extract. The solvent was subsequently removed under vacuum conditions using a rotary evaporator (KNF RC600, Germany). A 1 mL portion of the sample was obtained by centrifugation at 1,000 rpm for 5 minutes, allowing for the analysis of essential phytochemical constituents.

2.4 Environmental Conditions

Environmental parameter

Environmental parameters were gathered in triplicate at each durian tree on the day of collection. Four key environmental factors were assessed: temperature, relative humidity, soil moisture, and elevation above sea level. Temperature and relative humidity were measured using an automatic hygrometer (TSI® Model 9545/9545-A, VelociCalc®, United States of America) by recording these values within the radius of the canopy beneath the durian tree. Elevation and height above sea level for each tree were determined using a GIS meter (GPSMAP 66S, Garmin, Taiwan). The procedure involved aiming at the tree's base, waiting for the data to stabilize, and then recording the readings.

Soil Physiology Analysis

The particle size distribution method was used to examine soil texture in dried soil samples that were sieved through a 2 mm screen. The proportions of sand, silt, and clay were determined using the pipette method in accordance with USDA rules. The USDA soil texture triangle was used to determine soil texture [8]. Soil moisture measurements were gathered using the oven-drying method, which entailed removing branches and extraneous debris from the topsoil surrounding the tree prior to examination.

Soil Chemical Property Analysis

A pH meter was used to assess soil pH and electrical conductivity (EC) at a 1:2 ratio of soil to distilled water. Soil samples were sieved through a 0.5 mm mesh and evaluated for organic matter content using the Walkley-Black method [9]. Total nitrogen content was determined using the Kjeldahl method [10], while accessible phosphorus was determined using the Bray II method [11]. To analyze potassium, calcium, and sodium, soil samples were extracted using 1 M ammonium acetate (NH_4OAc) at pH 7. The concentrations of these elements were determined using an Atomic Absorption Spectrophotometer (AAS, Thermo iCE 3000 Series, USA). Model 410 Flame Photometer (Sherwood Scientific, UK) was used. To examine potassium, atomic absorption spectroscopy was used to assess calcium and sodium [12].

2.5 The morphology

2.5.1 Clinometer

The height of a large tree was estimated using the clinometer method, a method that involves angling [13]. The height of the entire tree is calculated as H1 = tan a(AC)+H2 where H is a height of the tree (Figure 2) where tan a is the angle formed by the tangent of the angle ABC, H_1 is the height of the tree from ground level to the top of the tree, and H_2 is the height of the tree from the ground to the eye level of the observer.

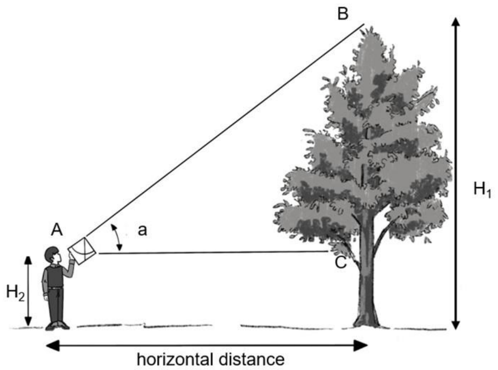

Figure 2. An instrument and method for measuring tree height by the clinometer method.

2.5.2 Diameter Distribution

Calculate the diameter of the stem. Take a tape measure and measure the circumference of the trunk at the height of the chest DBH (Diameter at Breast Height), then use the formula to calculate the trunk diameter as follows: $D = x / \pi$; where D = stem diameter, and x = circumference.

2.5.3 Crown cover

The surveyor's position appears like a sturdy pillar at the edge of the canopy due to the canopy's dimensions. To determine the distance to the canopy's edge from the opposite side in both the north-south and east-west directions, employ a tape measure and select the greater of the two values when obstructions are present. It may not be feasible to measure both sides due to limited access. To calculate the radius, measure the distance between two preliminary points using a tape measure. The diameter is subsequently found by doubling this length.

2.6 Geographical index analysis

Create a geographical map depicting the prevalence of KS durian trees within the regions of Ban Khao Thep Pitak Villages 1, 2, and 3, situated in Khao Phang sub-district, Ban Ta Khun District. This map is generated by integrating collected coordinates and environmental data into the mapping system. Tree coordinates are depicted using a three-dimensional framework, with the X-axis signifying latitude, the Y-axis signifying longitude, and the Z-axis representing various environmental variables, including altitude above sea level, temperature, soil pH, soil moisture content, and air humidity, for each data point.

2.7 Phytochemical screening

The unrefined extract was applied to TLC silica gel 60 F254 aluminium plates (10 cm x 20 cm, Merck, Switzerland), each with a 0.8 cm strip, using a Linomat-5 (CAMAG, Switzerland) and a Nitrogen aspirator. Two microliters of crude extract, at a concentration of 1 mg/mL, were spotted on the TLC plate. Subsequently, the TLC plates were developed in an ADC-2 Automatic Developing Chamber (CAMAG, Switzerland) with a mobile phase composed of toluene, acetonitrile, and ethyl acetate in a 35:5:15 ratio. The phytochemical profile was documented under white light, at 254 nm, and at 366 nm using the CAMAG TLC Visualizer2. Phytochemical groups were identified by applying specific reagents to the TLC plates bearing the phytochemical fingerprints and observing the reaction of the chemical groups. Alkaloids were treated with the Dragendorff reagent, and the plate was heated at 100°C for 5 minutes. The reaction was visualized as a red-orange color under 366 nm. Terpenoids and steroids were analyzed using the vanillin reagent, which was sprayed onto the plate, and then the plate was heated at 100°C for 5 minutes. The reaction appeared as a brown-purple color under 366 nm. Coumarins and anthraquinones were treated with the potassium hydroxide reagent, and the plate was heated at 100°C for 5 minutes. The reaction exhibited a blue-red color under 366 nm. Phenolics, phenols, terpenes, sugars, and steroids were identified using the p-Anisaldehyde reagent, which was sprayed onto the plate, and then the plate was heated at 100°C for 5 minutes. The reaction manifested as blue, red, gray, or green colors under 366 nm, respectively. Flavonoids were visualized under a 366 nm wavelength after the aluminum chloride reagent was sprayed and the plate was heated at 100°C for 5 minutes. To assess the phytochemical response on the TLC plate to the antioxidant test, a separate TLC plate was sprayed with a 0.5% 2,2-diphenyl-1-picrylhydrazyl (DPPH) solution in methanol. This action resulted in the substance turning yellow after a 5-minute incubation at room temperature in the dark.

2.8 Statistical analysis

To investigate the relationship between environmental factors and the longevity of a local durian tree using the program R (Ver 4.3.1 for Windows). The data were analyzed using a one-way analysis of variance (ANOVA). Significant differences were identified, and multiple comparisons were performed using Tukey's test at a 95% confidence level.

3. Results and Discussion

3.1 The evaluation of the geographical index

Geographic mapping was utilized to visualize the spatial distribution of native durian trees in the study area, integrating both coordinate data and environmental factors. Durian trees were categorized by age into five classes: 200-250 years, 150-200 years, 100– 150 years, 50-100 years, and less than 50 years. These categories were represented by different color-shaded symbols on the map (Figure 3). The durian trees were primarily distributed within a narrow geographic range, spanning latitudes 8.940–8.954 and longitudes 98.812–98.826. The surveyed area was characterized by a single access point and coordinates ranging from latitude 8.938 to 8.948 and longitude 98.818 to 98.824. A total of 83 durian trees were recorded, located in Villages 1, 2, and 3. Age classification, based on interviews with landowners, revealed that 12 trees were over 100 years old, 37 were between 50 and 99 years old, and 34 were younger than 50 years. Most trees were concentrated in Village 1, with no trees found in Village 2. In Village 3, four trees were recorded, including one over 100 years old and three aged between 55 and 99 years (Figure 3). The age distribution and spatial clustering patterns observed in this study are consistent with findings from similar research on durian populations in Southern Thailand and Peninsular Malaysia, where older trees are often concentrated in areas with long-term traditional cultivation practices and minimal land-use change [14]. Studies on other perennial tropical fruit trees, such as mangosteen and rambutan, have also reported that historical planting patterns, coupled with access to water sources and suitable microclimates, strongly influence the persistence of older trees [15]. The absence of trees in certain villages may reflect past land conversion, soil condition differences, or socioeconomic factors that limit durian cultivation, as noted in previous agroforestry studies [16]. This suggests that conservation of the oldest durian trees may require targeted protection measures in specific geographic zones, along with community-based initiatives to maintain genetic diversity and local heritage value.

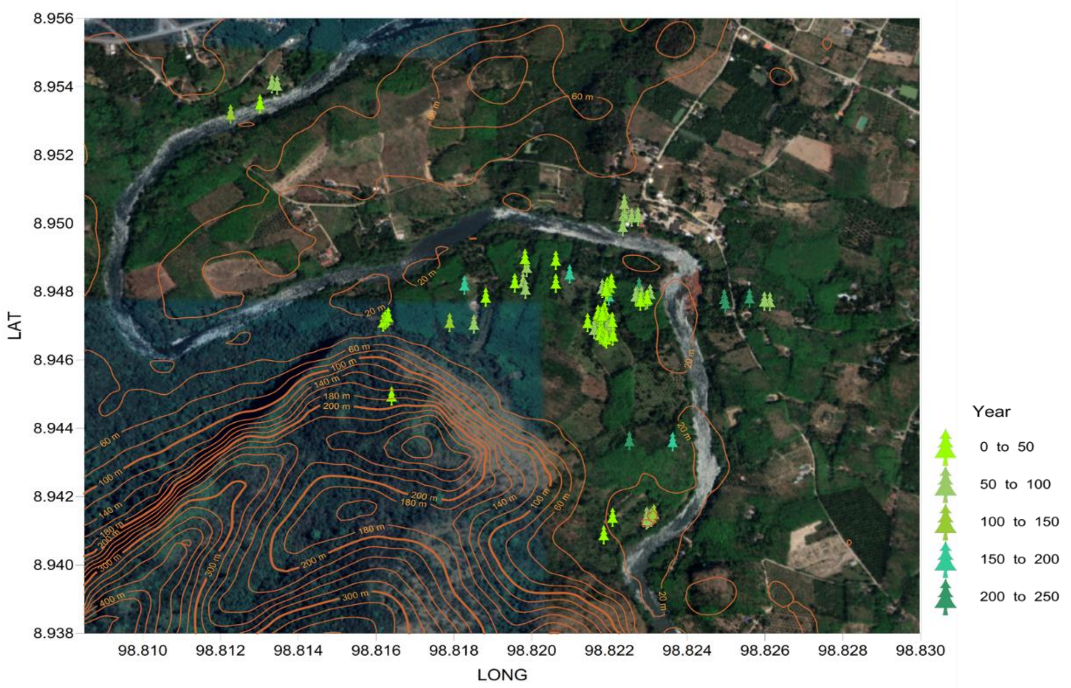

Figure 3. The distribution of the durian tree according to its age.

3.2 Environmental Characters

3.2.1 Elevation, Temperature, Soil Moisture, and Humidity

The study assessed environmental parameters, including elevation above sea level, ambient temperature, soil moisture, and relative humidity. Elevation ranged from 29 to 62 meters, temperature ranged from 26°C to 31°C, soil moisture content ranged from 9.5% to 14%, and air humidity ranged from 58.87% to 87.37%. A Chi-square analysis revealed a statistically significant correlation between tree age and temperature ($p < 0.05$). Durian cultivation is typically viable from 0 to 800 meters above sea level and within temperature ranges of 25–32°C. In comparison to traditional durian-growing regions in Indonesia, the study area showed slightly lower average temperatures (27–31°C), which may influence the distribution and persistence of native durians on Ternate Island [17]. Similar studies in Indonesia have reported durian growth at elevations ranging from 13 to 427 meters, with notable findings such as 58 indigenous durians aged over 50 years thriving at 400 meters above sea level in Ngawi, Indonesia [18]. Additionally, local durians from Batuah Village, aged 24–27 years, are known for their distinctive fragrance, which is attributed to specific humidity conditions (56–65%) and the presence of volatile sulfur and ester compounds [19]. In contrast, most pine trees can endure for up to 100 years within temperature ranges of 2.2 to 3.4°C [20], in comparison to other areas where traditional durian is also grown. Indonesia, in particular, discovered that the average temperature of the study area is lower than the air temperature, which ranges from 27-31°C during surveys, affecting the distribution and persistence of native durian on Ternate Island, Indonesia [17]. The results of the environmental factors assessment for durian (*Durio zibethinus*) planting in Pangkatan District, Labuhanbatu Regency, revealed that the temperature ranged between 25°C and 32°C [21]. The age of the durian tree, however, is not mentioned in the studies. Durians are grown at an average annual temperature of 27.8°C, providing volatile compounds and fragrances characteristic of the durian variety Durio zibethinus, which produces sulfur and esters, as well as aromatic compounds not typically found elsewhere. The durian was between 24 and 27 years old when it was discovered in Batuah Village, Loa Janan District, Kutai Kartanegara, East Kalimantan, Indonesia. This is possible because local durian has a stronger odor than other durian varieties [19]. The variety of the durian. The durian plantation in Gua Musang, Kelantan, was established at 26.4°C on a slope with the highest point 439 m above sea level and the lowest point 410 m above sea level.

The findings of this study indicate that the elevation range and microclimatic conditions of the surveyed area fall within the generally accepted thresholds for durian cultivation (0–800 m above sea level, 25–32°C). The slightly lower average temperatures recorded in the study area (27–31°C) compared to some traditional durian-growing regions in Indonesia may contribute to variations in fruiting patterns, flowering cycles, and overall tree longevity. Previous research in Ngawi, Indonesia, reported the successful cultivation of indigenous durians aged over 50 years at an elevation of 400 m above sea level, suggesting that moderate elevation, coupled with stable thermal conditions, can support long-term tree survival and maintain high fruit quality [22]. Elevation also influences soil moisture retention, as higher altitudes often exhibit cooler temperatures and reduced evapotranspiration rates, thereby affecting root water availability. Studies in East Kalimantan have shown that durians grown in areas with relative humidity levels between 56% and 65% develop distinctive aromatic profiles due to the enhanced biosynthesis of volatile sulfur compounds and esters, which are influenced by moisture-related metabolic pathways [19]. In contrast, excessive fluctuations in soil moisture can lead to nutrient leaching or waterlogging, both of which can stress the trees and alter fruit chemistry.

3.3 Physical Properties of Soil by Tree Age

The analysis of soil texture revealed that all durian trees grew in soils with a silty texture. A one-way ANOVA demonstrated statistically significant differences in soil characteristics by age group at the 99% confidence level ($p < 0.001$, $F(10, 22) = 42.96$). The silt content ranged from 81.93 ± 0.42% to 95.51 ± 0.56%, with the highest sand proportion in the 0–10-year group and the lowest in the 100–200-year group. Soil moisture content also varied significantly ($p < 0.001$, $F(10, 22) = 7.218$), ranging from 11.73 ± 0.49% to 15.93 ± 0.64%. The highest moisture was recorded in the 100–200-year group and the lowest in the 40–50-year group (Table 1).

3.4 Chemical Properties of Soil by Tree Age

The soil chemical composition varied significantly with the age of the durian trees. Soil pH ranged from 4.43 ± 0.02 (90–100 years) to 5.93 ± 0.04 (100–200 years), with significant differences detected ($p < 0.001$, $F(10, 22) = 1.469$). Electrical conductivity (EC) values ranged from 44.23 ± 0.25 to 173.70 ± 0.15 mS/cm ($p < 0.001$, $F(10, 22) = 3.365$). Organic matter (OM) content also showed significant variation ($p < 0.001$, $F(10, 22) = 689.8$), ranging from 1.23 ± 0.03% (70-80 year group) to 2.89 ± 0.02% (40-50 year group), with the highest OM content in the 40–50-year group. Soil nitrogen levels ranged from 667.10 ± 1.96 to 2,365.00 ± 31.27 ppm ($p < 0.001$, $F(10,22)=6.202$), with the 50–60-year group exhibiting the highest content. Phosphorus content varied from 1.55 ± 0.22 to 32.72±0.17 ppm ($p < 0.001$, $F(10,22)=16.113$), and potassium levels ranged from 34.67±0.06 to 72.47 ± 0.06 ppm ($p < 0.001$, $F(10,22)=1.264$), peaking in the 80–90-year group. The calcium content significantly differed across age groups ($p < 0.001$, $F(10, 22) = 10.740$), ranging from 25.67 ± 0.59 to 487.80 ± 0.55 ppm. Sodium also showed variation ($p < 0.001$, $F(10, 22) = 1.324$), with values from 10.34 ± 0.17 to 98.60±0.46 ppm. These results suggest that the age of the durian tree plays a significant role in influencing the chemical characteristics of the surrounding soil (Table 2).

Table 1. Physical properties of soil according to the age range.

Age range (years)	Physical properties of soil				Soil type
	soil particles			Soil moisture content (%)	
	Sand (%)	Silt (%)	Clay (%)		
0-10	1.44 ± 0.032	95.51 ± 0.563	3.05 ± 0.538	13.53 ± 1.147	Silt
10-20	1.59 ± 0.053	91.76 ± 0.208	6.35 ± 0.256	13.03 ± 0.954	Silt
20-30	1.39 ± 0.022	87.70 ± 0.332	10.91 ± 0.310	14.00 ± 1.041	Silt
30-40	1.47 ± 0.035	94.15 ± 0.048	4.38 ± 0.070	14.23 ± 0.452	Silt
40-50	1.43 ± 0.041	94.42 ± 0.337	4.14 ± 0.323	11.73 ± 0.493	Silt
50-60	1.44 ± 0.046	95.42 ± 0.141	3.14 ± 0.168	15.33 ± 0.746	Silt
60-70	1.75 ± 0.048	94.79 ± 0.242	3.45 ± 0.262	15.57 ± 0.572	Silt
70-80	1.52 ± 0.012	95.47 ± 0.258	3.00 ± 0.245	14.50 ± 0.980	Silt
80-90	1.46 ± 0.044	92.87 ± 0.236	5.66 ± 0.218	14.73 ± 0.666	Silt
90-100	1.72 ± 0.045	92.71 ± 0.235	5.56 ± 0.275	14.20 ± 0.361	Silt
100-200	1.40 ± 0.010	81.93 ± 0.420	16.67 ± 0.426	15.93 ± 0.642	Silt

Note: all pairs of the age of the tree show a statistically significant result at $p < 0.05$

Soil chemical properties, including organic matter, pH, and concentrations of macro- and micronutrients, were observed to vary with tree age in this study. Older trees (over 100 years) were generally associated with soils richer in organic matter and available potassium, possibly due to prolonged litter fall and root turnover that contribute to nutrient cycling. This finding is consistent with those from durian agroforestry systems in Malaysia, where older stands exhibited higher cation exchange capacity (CEC) and greater microbial biomass, indicating healthier rhizosphere activity [23]. Younger trees, in contrast, were often found in soils with lower organic carbon and reduced nutrient retention, which could be attributed to more recent land conversion or less developed root systems. Humidity and soil moisture levels further interact with soil chemistry by influencing microbial decomposition rates and the mineralization of nutrients. High humidity can enhance the breakdown of organic matter, increasing the availability of nitrogen and phosphorus—nutrients essential for flowering and fruit set [24]. Conversely, in poorly drained soils, high moisture levels may promote anaerobic conditions, leading to reduced nutrient uptake efficiency and potential accumulation of phytotoxic compounds.

3.4 Morphological character

The morphology of the Khlong Saeng (KS) native durian trees was evaluated using three key parameters, which consisted of fruiting cycle length, tree height, and crown cover—all of which showed significant correlations with tree age. Notably, the fruiting cycle length demonstrated statistically significant relationships with age (Figure 4a), tree height (Figure 4b), and crown cover (Figure 4c).

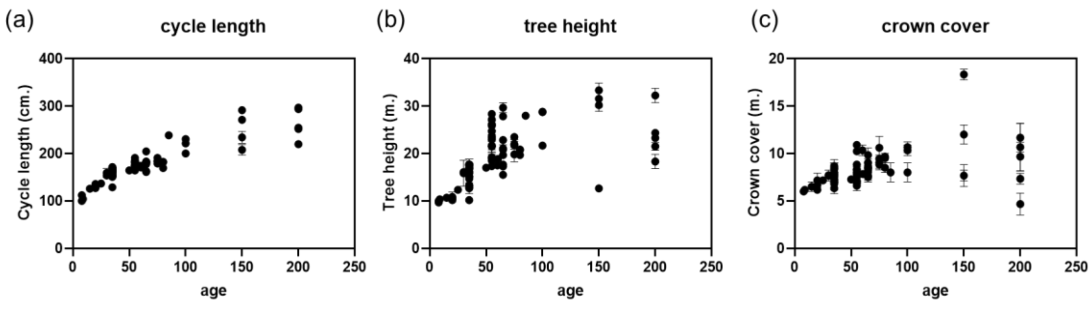

Figure 4. Correlation between tree age and morphological characteristics: (a) cycle length, (b) tree height, and (c) crown cover of native durian trees.

Table 2. Chemical properties of soil according to the age range.

Age range (years)	Chemical properties of soil							
	Soil pH	**EC mS/cm**	**OM (%)**	**N (ppm)**	**P (ppm)**	**K (ppm)**	**Ca (ppm)**	**Na (ppm)**
0-10	5.32 ± 0.018	173.70 ± 0.152	2.32 ± 0.023	885.20 ± 4.790	9.27 ± 0.070	63.43 ± 0.212	467.20 ± 1.689	33.50 ±0.302
10-20	5.27 ± 0.031	106.10 ± 0.148	1.50 ± 0.027	1326.00 ± 6.202	2.07 ± 0.074	53.77 ± 0.056	327.40 ± 0.381	34.60 ± 0.200
20-30	5.42 ± 0.024	69.30 ± 0.202	1.52 ± 0.031	962.80 ± 0.868	8.567 ± 0.088	51.43 ± 0.119	355.70 ± 1.613	32.50 ± 0.345
30-40	4.82 ± 0.020	75.20 ± 0.168	2.15 ± 0.060	1465.00 ± 9.741	1.55 ± 0.217	56.17 ± 0.122	234.10 ± 0.954	33.50 ± 0.608
40-50	4.71 ± 0.017	77.60 ± 0.103	2.89 ± 0.020	1129.00 ± 2.013	7.69 ± 0.183	55.80 ± 0.100	326.00 ± 1.012	26.20 ± 0.561
50-60	5.92 ± 0.022	72.37 ± 0.355	1.75 ± 0.014	2365.00 ± 31.270	32.72 ± 0.165	54.87 ± 0.064	487.80 ± 0.550	10.34 ± 0.173
60-70	4.82 ± 0.024	44.23 ± 0.251	1.61 ± 0.018	838.30 ± 5.227	7.83 ± 0.112	34.67 ± 0.059	110.90 ± 0.352	32.40 ± 0.000
70-80	5.42 ± 0.026	52.80 ± 0.200	1.23 ± 0.025	667.10 ± 1.956	5.60 ± 0.055	56.53 ± 1.672	207.10 ± 0.664	10.80 ± 0.357
80-90	5.72 ± 0.018	90.80 ± 0.204	2.53 ± 0.035	1713.00 ± 12.115	19.66 ± 0.131	72.47 ± 0.063	142.80 ± 0.403	11.17 ± 0.254
90-100	4.43 ± 0.015	65.97 ± 0.227	1.52 ± 0.022	1280.00 ± 4.056	8.25 ± 0.016	50.77 ± 0.057	25.67 ± 0.585	98.60 ± 0.458
100-200	5.93 ± 0.035	79.03 ± 0.849	2.16 ± 0.067	723.60 ± 2.560	2.573 ± 0.134	37.27 ± 0.048	385.80 ± 0.061	25.27 ± 0.671

Note: all pairs of the age of the tree show a statistically significant result at $p < 0.05$

For trees aged 200 years, the average fruiting cycle length was 263.20 ± 4.59 cm, while trees aged over 100 years had a cycle length of 247.64 ± 5.08 cm. Trees aged 50–99 years exhibited an average of 179.02 ± 2.62 cm, and those younger than 50 years had a cycle length of 149.59 ± 3.07 cm. In terms of tree height, trees aged over 100 years averaged 25.60 ± 0.99 m, slightly higher than the 200-year-old group (24.94 ± 1.02 m). Trees aged 50–99 years had an average height of 21.83 ± 0.78 m, while those under 50 years measured 14.12 ± 0.72 m on average. For crown cover, 100-year-old trees had the largest average (9.89 ± 1.06 m^2), followed by 200-year-old trees (8.93 ± 1.27 m^2), 50–99-year-old trees (8.40 ± 0.51 m^2), and the youngest group under 50 years (7.32 ± 0.42 m^2). These findings indicate a positive correlation between tree age and fruiting cycle length. Older trees generally exhibit longer fruit development periods, which could influence resource allocation, hormonal regulation, and physiological processes as the tree matures [25, 26]. While environmental conditions were not directly compared across age groups in this study, it is possible that long-term exposure to local conditions also contributes to these trends. The crown cover, reflecting the canopy spread, typically increases with age as trees expand their branching to maximize sunlight capture [27]. The observed peak in crown cover among trees over 100 years, followed by a slight decline in the 200-year group, may be attributed to natural senescence, branch dieback, or historical pruning practices. These morphological traits—cycle length, height, and crown spread—are valuable indicators of developmental stages in KS native durian trees and could be used to estimate tree age in the absence of planting records. Given the correlation between morphological traits and fruit yield, understanding these age-related patterns can support better orchard management. Tailoring interventions such as pruning or fertilization based on tree age and morphological characteristics could enhance productivity and sustainability.

During fieldwork, durian samples were collected from trees aged 30 to 70 years, with a focus on fruit-bearing specimens. Trees were selected from multiple gardens across the region to assess morphological diversity among KS local varieties. In a related study in North Aceh, Indonesia, durian trees ranged in age from 20 to 200 years, with heights between 20 and 83 meters, and exhibited variations in trunk and leaf color associated with age and site-specific water availability. Notably, optimal yields of 200 fruits per tree were observed at elevations between 0 and 910 meters, with temperatures ranging from 22 to 46°C, and a relative humidity of around 30%, for trees aged 80–150 years. In Malaysia, durian trees aged 25 to 150 years grew under 50–80% humidity and at temperatures of 25–32°C, reaching heights of 18.5–38 meters. Our KS samples were labeled KS1–KS6, with respective tree heights: KS1 (24.67 m), KS2 (18.83 m), KS3 (13.33 m), KS4 (19.17 m), KS5 (15.87 m), and KS6 (19.67 m). Their fruiting cycle lengths were: KS1 (181.67 cm), KS2 (170.67 cm), KS3 (168.67 cm), KS4 (176.00 cm), KS5 (159.00 cm), and KS6 (177.67 cm). Crown cover measurements were as follows: KS1 (6.60 m), KS2 (7.83 m), KS3 (7.50 m), KS4 (8.83 m), KS5 (7.67 m), and KS6 (8.50 m).

Figure 5. The local durian in Surat Thani Province. Local names Khlong-Saeng Durian; KS1 = Mang Khut, KS2 = Mum Fai, KS3 = Khiao Thawai, KS4 = Thang Lot, KS5 = Gan Petch, and KS6 = Kor Trong.

The analysis of fruit shape among these samples identified four major categories: globose (KS5, KS6), oblate (KS2, KS4), elliptic (KS1), and obovoid (KS3). Flesh color was classified into dark yellow and soft yellow types. Native durians in Thailand typically exhibit an oval fruit shape, weigh between 2.20 and 3.42 kg, and have bright yellow flesh [28]. In contrast, local durians in Ternate, Indonesia, exhibit oval-spherical thorns, white skin, and yellowish-brown, oval-shaped seeds [29]. Environmental conditions significantly impact the longevity and productivity of durian trees. Previous studies have shown that optimal durian growth occurs at 20–30°C [30], under suitable conditions of air humidity, soil pH, and moisture. Excessive moisture, however, can lead to rot and fungal diseases. In Malaysia, soil pH values of 6.88–7.60 and soil moisture levels of 57.37–67.07% were found to be optimal [31]. In contrast, this study observed a slightly more acidic soil pH, ranging from 5.67 to 6.33. A related Indonesian study found that durian trees at elevations of 200–250 meters produced both rectangular and oblate fruits, with textures ranging from white to pale-yellow to lemon yellow [32]. Furthermore, the highest durian pollen germination rate (63%) was reported in Thailand at 30°C, highlighting temperature as a key factor for reproductive success [33]. The local durian varieties in Surat Thani province exhibit diverse morphological and organoleptic traits, reflecting both genetic diversity and adaptation to the province's unique environmental conditions. In this study, four distinct fruit shape categories were identified—globose, oblate, elliptic, and obovoid—suggesting that multiple landraces or locally adapted lines are present within the region. Such variation is consistent with previous reports on native Thai durians, which often exhibit an oval or oblong fruit shape, medium to large fruit size (2.20–3.42 kg), and bright yellow flesh coloration [28]. The variation in shape may influence both consumer preference and market value, as shape uniformity is often associated with commercial grading standards, while unique forms can attract niche markets. Flesh color variation, observed here as dark yellow and soft yellow, may be linked to differences in carotenoid and flavonoid concentrations, which not only influence appearance but may also contribute to antioxidant properties [34]. The color spectrum observed in Surat Thani durians aligns with reports from other Southeast Asian regions, such as Indonesia's Ternate durians, where seed color and skin tone vary markedly depending on environmental conditions [17].

Environmental factors in Surat Thani appear to play a central role in shaping both tree longevity and fruit quality. The province's climate, with average temperatures often ranging between 27 °C and 31°C, falls close to the optimal range of 20 °C to 30°C for durian growth and reproduction. However, the slightly more acidic soil pH recorded in this study (5.67–6.33) differs from the neutral to slightly alkaline conditions (pH 6.88–7.60) reported as optimal in Malaysia [31]. This suggests that Surat Thani durians may possess a degree of tolerance to moderately acidic soils, a trait potentially advantageous in tropical zones with high rainfall and leaching rates. Soil moisture levels, although not explicitly reported in the result segment, are critical in durian cultivation. Excessive moisture can predispose trees to root rot and fungal infections [35]. The slightly acidic soils of Surat Thani may also affect nutrient availability, particularly of calcium and magnesium, which are essential for fruit development and structural integrity. The durability of durian trees in such conditions may indicate long-term ecological adaptation, supporting the survival of certain landraces despite less-than-optimal pH levels. From a reproductive biology perspective, the success of pollen germination is highly dependent on temperature. The highest germination rate reported in Thailand (63% at 30°C) [33] is consistent with the prevailing temperature range in Surat Thani, potentially explaining the sustained productivity of older trees in the region. When compared to Indonesian durians grown at higher elevations (200–250 m) with diverse fruit shapes, Surat Thani's local varieties may prioritize flavor and flesh color consistency over morphological extremes, possibly due to market preferences and historical selection by farmers. Overall, the morphological diversity, flesh color variation, and environmental resilience of local durians in Surat Thani suggest a well-adapted population with significant potential for selective breeding and premium branding. These characteristics, combined with the province's established reputation as a major durian-producing area in southern Thailand, provide strong opportunities for value addition through cultivar registration, geographical indication (GI) labeling, and agritourism initiatives. Future studies should integrate genetic analysis with detailed sensory profiling to better understand the linkage between genotype, phenotype, and environmental adaptation in these local varieties.

3.5 Phytochemicals and antioxidant effects of DPPH on TLC plate

The phytochemical analysis of crude durian peel extract, using the derivatized reagent method, revealed the presence of five distinct groups of substances: terpenoids, steroids, phenolics, phenols, and sugar esters. These findings are summarized in Table 3.

Table 3. Phytochemicals of crude durian peel extract.

Phytochemicals	reagents	crude durian peel extract						
		KS1	KS2	KS3	KS4	KS5	KS6	KS7
Terpenoid	Vanillin	-	-	-	+	+	+	+
Steroids	Vanillin	-	-	-	+	+	+	+
Phenolic	Aluminium chloride	+	+	+	+	-	-	+
Phenol	p-Anisaldehyde	+	+	-	-	-	-	-
Sugar steroid	p-Anisaldehyde	+	+	-	-	-	-	-

Note: + means positive result; - means negative result. Local names Khlong-Saeng Durian; KS1 = Mang Khut, KS2 = Mum Fai, KS3 = Khiao Thawai, KS4 = Thang Lot, KS5 = Gan Petch, KS6 = Kor Trong and KS7 = Sho Nui

Terpenoid compounds were evident in extracts KS4, KS5, KS6, and KS7, with steroid compounds also being apparent in these same extracts. Phenolic substances were found in KS1, KS2, KS3, KS4, and KS7, and distinct phenolic compounds were detected in KS1 and KS2 extracts. Furthermore, steroid substances were identified explicitly in extracts KS1 and KS2, as outlined in Table 2. The DPPH assay demonstrated the antioxidant activity of the crude durian peel extract, with results shown on the TLC plate in Figure 6. This test visualized the antioxidant properties of various compounds in the extract.

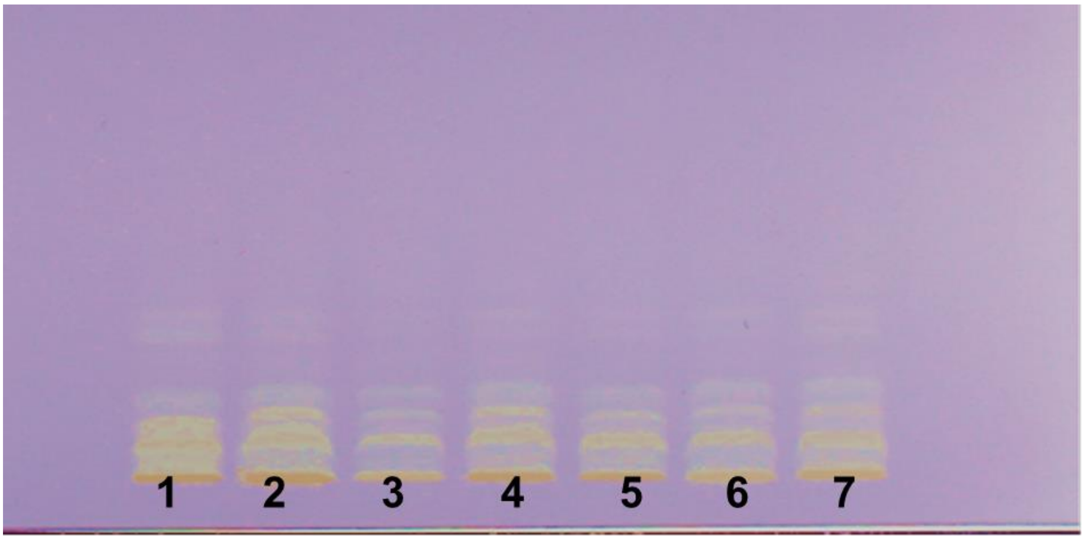

Figure 6. Antioxidant activity of the durian peel extract, assessed via DPPH reaction on a TLC plate under white light illumination at room temperature.

Durian fruit peels are often seen as environmental waste due to the high volume of byproducts, particularly during the blooming season in plantation areas. The growing emphasis on zero waste in agriculture has led to increased interest in utilizing durian peels [36-37]. In this study, the crude peel extract was tested for antioxidant activity using TLC screening. Previous studies have also investigated durian peels as potential raw materials with pharmacological properties that target issues such as diabetes, dental caries, and root canal infections. These investigations explored the antioxidant activity in durian peels, aiming to uncover bioactive compounds that could serve as nutraceuticals with antioxidant, anti-inflammatory, and health-promoting benefits [38, 39]. The TLC plate clearly showed that the crude durian peel extract contains multiple compounds exhibiting antioxidant activity. The presence of yellow spots (1-7) on the TLC plate suggests that several phytochemicals contribute to this effect. This aligns with the screening results (Table 3), where terpenoids, steroids, and phenolic compounds were identified, all of which likely separate and contribute to the antioxidant activity observed on the TLC plate (Figure 6). This study underscores the potential of durian peels, often discarded as agricultural waste, as a valuable source of natural antioxidants. This aligns with the growing movement to valorize food waste and identify sustainable sources of bioactive compounds for various applications in pharmaceuticals, nutraceuticals, and food preservation [40]. Given the high volume of durian peels generated, the study highlights their untapped potential for high-value applications due to their rich phytochemical content. Moreover, durian peels have been traditionally explored for their pharmacological properties, particularly in managing diabetes, dental caries, and root canal infections, further emphasizing the importance of studying their bioactive components.

4. Conclusions

This research on the Khlong Saeng native durian has provided significant insights into the morphological characteristics, environmental factors, and phytochemical properties of these trees, contributing to a better understanding of their development, ecological significance, and potential agricultural value. Morphological Character: The study found a significant correlation between tree age and morphological traits, including fruit cycle length, tree height, and crown cover, with older trees showing longer fruit cycles, greater height, and larger crown covers. Environmental Factors: The growth and age of the durian trees were influenced by local environmental conditions, including temperature, humidity, and soil properties, which varied across different regions. Phytochemicals and Antioxidant Effects: Phytochemical analysis of durian peel extracts revealed the presence of terpenoids, steroids, and phenolic compounds, with antioxidant activity demonstrated through DPPH reaction on a TLC plate, indicating the potential for bioactive applications. This highlights the untapped value of durian peel waste in the pharmaceutical and nutraceutical industries. Future research could focus on isolating specific bioactive compounds from durian peels and evaluating their therapeutic potential for human health. In addition, the findings could be utilized to develop sustainable agroforestry practices that protect native durian biodiversity while enhancing the income of local farmers. Establishing guidelines for selective breeding, conservation zoning, and value-added product development could ensure the long-term preservation and economic viability of Khlong Saeng native durians.

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