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Research article

Phytochemical and Physicochemical Characterization and Heritability Estimates of Fruit Quality Traits in Selected Coconut (*Cocos nucifera* L.) Populations

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Abstract: Limited information exists on the antioxidant performance of coconut cultivars. This study evaluated the phytochemical and physicochemical profiles of fruit quality traits and assessed genetic variability in response to free-radical-induced damage. Data were analyzed using one-way ANOVA at a 95% confidence level, with genetic parameters computed in RStudio v4.2 and graphical representations generated using OriginLab Pro 2024 v10.1. Results indicated that total phenolic content (TPC) was highest in the Tagnanan population (78.54±2.95), followed by hybrid Matag (62.2±2.60). Total flavonoid content (TFC) similarly peaked in Tagnanan (91.83±7.34), with hybrid Matag recording a comparable value (79.42±7.93). DPPH radical inhibition was greatest in Malayan Dwarf and Tagnanan Tall (58.97±1.21 and 58.26±1.00, respectively). Phenotypic coefficients of variation were 26.46% for TPC, 23.28% for TFC, and 5.87% for DPPH. Corresponding genotypic variations were 25.12%, 21.35%, and 4.85%. Heritability estimates were highest for TPC (90.13%) and TFC (84.09%). Genetic advancement as a percentage of the mean (GAM) indicated gains of 49.13% and 40.33% for TPC and TFC, respectively, whereas DPPH scavenging activity showed only 8.25% genetic gain. Physicochemical analysis identified hybrid Matag and Malayan Dwarf as having the highest protein content (16.77% and 16.47%). Hybrid Matag recorded the highest punching force (109.91±0.33 N) and total soluble solids (5.71%), exceeding those of its parental materials. Tagnanan Tall demonstrated superior antioxidant potential, while hybrid Matag combined strong antioxidant traits with excellent physicochemical properties. Both cultivars are recommended for priority inclusion in coconut breeding programs, with multi-location trials advised to validate findings across diverse environments.

Keywords: Phytochemical; physicochemical; antioxidant; genetic variability; coconut

1. Introduction

Coconut (*Cocos nucifera* L.) is an important plantation crop worldwide, cultivated in over 93 countries and providing livelihoods for millions of people [1]. As a staple crop in many tropical areas, it is often called the "tree of life," emphasizing its economic and cultural significance [2]. Despite intense competition from oil palm and soybean, it remains a vital resource for small-scale farmers in tropical regions [3]. Significant investment is directed toward edible products made from coconut oil and its kernel, sugar, coconut water, fiber, coco peat, and charcoal, produced in various regions [4]. It thrives on poor soils where other crops fail, requires minimal intensive management, and produces a wide array of products for both domestic use and local and international markets [3]. Polyphenolic compounds are significant secondary

metabolites present in both the edible and non-edible parts of the plants. These plant-derived polyphenols, recognized for their antioxidant properties, have been linked to numerous health benefits, including mitigating the effects of aging and reducing the risk of cancer and cardiovascular disease [5]. The importance of natural phenolic compounds from plant sources is gaining increasing attention from scientists, food producers, and consumers [6]. Regular intake of raw vegetables and fruits abundant in polyphenols is hypothesized to enhance conditions associated with degenerative diseases, including diabetes, cancer, hypertension, and cardiovascular disorders [7]. Coconut flesh is currently underutilized, but identifying its polyphenol compounds and antioxidant potential could transform it into a valuable commercial source. Natural antioxidants, such as those from coconut flesh, are gaining interest due to their safety and fewer side effects than synthetic alternatives [8].

Assessing genetic variability in crops is essential for sustainable production, as crop improvement and genetic diversification rely on the existing variability available to breeders [9]. Genetic divergence analysis measures variation among selected germplasms, facilitating breeders in the targeted selection of genetically diverse parent plants for the efficient implementation of heterosis breeding [10]. Partitioning variability into heritable and non-heritable components enhances our understanding of selection efficiency [11]. Estimates of genotype and phenotype coefficients of variation reveal the level of genetic variability in each germplasm. However, the key factor is the heritable portion of that variation, which significantly influences trait improvement through selection. Assessing heritability alongside genetic advancement enables more effective selection by minimizing environmental effects on total variation, thereby enabling precise identification of potential genotypes. Heritability values (h^2) for a trait can be estimated as the slope of a linear regression of mean values in parents and their progeny [12]. Estimating heritability and genetic advance is crucial for identifying the heritable portion of variability and the genetic gains expected in future generations [13]. High values of the genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), and heritability, coupled with significant genetic gains for total phenols and antioxidant potential, indicate that traits are predominantly governed by additive gene effects, making them dependable targets for effective selection strategies [14]. The PCV is significantly higher than the GCV for most traits, suggesting that environmental factors exert varying levels of influence across the measured characteristics [15]. Genotypes are identified by their physical traits, while genetic advance helps guide selection. Understanding heritability and genetic progress enables breeders to select the best parents for a successful, productive breeding program [15]. Genetic advance indicates the increase in the performance of selected lines relative to the actual population. High genetic advancement provides greater potential for selecting and improving yield-related traits. However, high heritability does not often guarantee high genetic advancement, as reported by Meena et al. [13]. High heritability and high genetic advance as a percentage of the mean are better predictors of selection success than heritability alone [10]. Traits with high heritability and moderate genetic advancement suggest that selecting such traits for improvement can be effective, indicating an important role of non-additive gene action in their inheritance.

Coconuts mature between eleven and thirteen months, during which the water volume inside decreases. Numerous studies have investigated the physicochemical and nutritional properties of coconuts at different maturity stages and cultivars. However, the current study on the physicochemical, phytochemical, and antioxidant properties of the hybrid Matag and its parental materials remains inadequate. No prior study has quantified the heritability and genetic advance of phytochemical traits (TPC, TFC, DPPH) in Tagnanan Tall, Malayan Dwarf, and their F1 hybrid Matag under Malaysian growing conditions, leaving a gap in the literature on the genetic control and selection potential of these health-relevant traits in tropical coconut populations. Therefore, the overall objective was to demonstrate and elucidate how parental materials contributed to the development of pure hybrid Matag in terms of physicochemical and phytochemical contents and antioxidant properties within the populations, and to examine variability, inheritance, and predicted genetic gains in the hybrid population.

2. Materials and Methods

The 22 individuals used for this study comprised palm trees sampled from the three populations (approximately 7 and 8 per population, using a convenience sampling approach) at Pusat Pertanian Teluk Bharu Perak, Malaysia, with a site description of clay-loam soil, a humid tropical climate, and ≤ 15 m elevation at 4°43′N, 100°57′E. The samples were distributed and adopted in a completely randomized design (CRD). The flesh of fresh coconut fruits was collected at full maturity, usually 11 to 12 months after flowering, from the three coconut populations: Tagnanan tall, Malayan red and yellow dwarf, and the hybrid Matag. The flesh was carefully removed from the husk and shell, then cut into smaller pieces for oven-drying. The samples were further ground into fine powder and labeled for further analysis. Selections were made by the palm populations based on the number of mature palms available at the time of data collection.

2.1 Phytochemical Compounds

The total phenolic and flavonoid contents, and the percentage of DPPH free radical scavenging activity were determined. Gallic acid by the Gutfinger [15] method and quercetin by the Zhishen et al. [16] method were used to determine total phenolic and flavonoid contents, respectively, with methanol as the extraction solvent. Folin Ciocalteu reagent, aluminum chloride, sodium carbonate, sodium hydroxide, sodium nitrate, and distilled water were used in the estimation of total phenols and flavonoids in test samples. Instruments used include cotton wool, micropipette 1000, mortar and pestle, orbital shaker, 50 ml Falcon tubes, conical flask, and UV-VIS spectrophotometer (Thermo Fisher Scientific, Multiskan Go UK) for measuring the absorbance of test samples. The antioxidant activity percentage of each sample was determined using the DPPH (2,2-diphenyl-1-picryl-hydrazyl) free radical assay, a standard technique for measuring DPPH. Individual palms from the study populations were used. The fruits were gently dehusked, and the flesh was manually removed from the shell using a flesh remover. The collected flesh was stored at -20 ºC for further analysis. The flesh was oven-dried for 5 hours at 105ºC, then cut into slices and ground to a fine powder in a mechanical grinder. The finely powdered material was sieved to have a homogeneous particle size ready for solvent extraction. Although this protocol may lead to some thermal degradation of heat-labile phenolics, further studies are recommended to consider freeze-drying or low-temperature vacuum drying to minimize this effect and obtain higher TPC and TFC estimates. Extraction of the solvent was carried out according to the protocol of Kaewseejan and Siriamornpun [17], with some modifications: 5 g of the powdered sample was weighed into a test tube, mixed with 20 ml of 80% methanol, and wrapped in aluminum foil to prevent light penetration. The solution mixture was further agitated for 1 hour on an orbital shaker, and the aqueous extract was obtained after filtering the mixture through filter paper (Whatman number 1). These extracts were then used for phytochemical determinations [18].

2.2 Determination of Total Phenolic Content (TPC)

A gallic acid stock solution was prepared by dissolving 0.1 g of gallic acid in 100 mL of water in a 100 mL volumetric flask. Double-distilled water was added to dilute, and the 100 mL mark was set; the mixture was stirred until completely dissolved in the dark to obtain a homogeneous solution. Different concentrations of the stock solutions (50, 100, 150, 200, 250, and 300 μg/mL) were prepared in a separate 100 mL volumetric flask. Each concentration was diluted to a final volume of 100 mL with double-distilled water in a dark place. Absorbance for each concentration was measured in triplicate using a microplate reader (UV-Vis Spectrophotometer, Thermo Fisher Scientific, Multiskan Go, UK) at 765 nm, yielding a six-point calibration curve over 50–300 μg/mL ($y = 0.0084x + 0.0891$, $R^2 = 0.9879$). The calibration curve was generated using the average absorbance values measured at various concentrations of gallic acid. The total phenolic content (TPC) of the coconut flesh extract was analyzed according to the method of Gutfinger [15], with slight modifications. A stock solution of 10 μg/mL gallic acid in distilled water was prepared to create a standard calibration curve ranging from 50 to 300 μg/mL in a 96-well microplate. A 200 μL aliquot of the extract was mixed with 1 mL of 10% Folin-Ciocalteu phenol reagent, then thoroughly mixed and incubated for 5 minutes. Subsequently, 800 μL of 7.5% sodium carbonate (Na_2CO_3) solution was added to the mixture. The prepared mixture was incubated for 30 minutes in the dark at room temperature. Absorbance readings were recorded at 765 nm using a microplate reader (UV-Vis Spectrophotometer; Thermo Fisher Scientific, Multiskan Go, UK).

Measurements were performed in triplicate, and distilled water was used as a blank control. The TPC was determined using an equation derived from the gallic acid calibration curve, and the results were expressed as milligrams of gallic acid equivalent (mg GAE/g) per gram of dry coconut flesh.

2.3 Determination of Total Flavonoid Content (TFC)

Exactly 10 mg of quercetin was dissolved in 10 mL of 80% methanol to prepare a stock solution. Serial dilutions were prepared from the stock solution at concentrations of 500, 250, 125, 62.5, 31.25, and 15.625 μg/mL. The absorbance at 425 nm was measured with a UV-Vis spectrophotometer ($y=0.0018x+0.0856$, $R^2=0.9845$) to generate a quercetin standard curve for total flavonoid content (TFC) analysis. Each concentration was measured in triplicate, and the calibration curve was plotted using the average absorbance values. The TFC was determined following the method of Zhishen et al. [16], with some modifications. For each sample, 1 mL of aqueous extract was mixed with 0.3 mL of 5% sodium nitrate ($NaNO_3$) solution. After 5 minutes, 0.3 mL of 10% aluminium chloride ($AlCl_3$) was added, followed by 2 mL of 1 M sodium hydroxide (NaOH) after 6 minutes. The total volume was adjusted to 10 mL with distilled water, and the mixture was thoroughly mixed. Absorbance was measured at 425 nm using a UV-Vis Spectrophotometer (Thermo Fisher Scientific, Multiskan Go, UK). A blank solution containing all reagents except quercetin was used as a control, and absorbance values were compared with the standard curve to determine the equivalent quercetin concentration. The total flavonoid content was expressed as mg of quercetin equivalents (mg QE/g) per dry weight of the coconut flesh. The TFC was calculated using the linear equation derived from the quercetin calibration curve.

2.4 Preparation of Stock Solution and Determination of DPPH Antioxidant Activity

A 0.1 mM DPPH working solution was prepared by dissolving 0.0224 g of DPPH powder in 100 mL of 80% methanol. The resulting purple mixture was homogenized and stored in a dark bottle at room temperature for later use. The DPPH free radical scavenging activity of the extracts was measured using a modified method from Brand-Williams et al. [19]. In this procedure, 2,850 μL of the fresh DPPH solution was combined with 150 μL of the extract, and the mixture was incubated in the dark for 30 minutes. The absorbance was measured at 510 nm using a UV-Vis spectrophotometer (Thermo Fisher Scientific, Multiskan Go, UK), and the percentage of DPPH inhibition was calculated using the equation:

$$\% \text{ DPPH} = [(\text{Absorbance control} - \text{Absorbance sample}) / \text{Absorbance control}] \times 100$$

Where, Absorbance control = DPPH solution's absorbance without extracts; Absorbance sample = DPPH solution's absorbance with sample extracts.

2.5 Physicochemical Properties

Samples were analyzed for physicochemical characteristics, with data collected in triplicate (analytical, not biological, replicates were performed on each fruit sample). Protein content was calculated using the AOAC 2001.11 standard for the Kjeldahl nitrogen percentage determination in the flesh, using a multiplication factor of 6.25. For every gram of nitrogen in the flesh, there is approximately 6.25% protein. The pH of the flesh was measured using a digital pH meter after the flesh (10 g) was grated and blended with 30 mL of distilled water in a 1:3 ratio. The pH meter was calibrated before the measurements using buffer solutions with pH 4.01 and 7.0. The total soluble solids (TSS) were expressed as °Brix, and the blended sample fruits were filtered and measured with a digital refractometer. Fresh fruit firmness was measured using a penetrometer texture analyzer with a pressure gauge in kg, and the values were converted to newtons (N). The moisture content and dry matter weight were evaluated by drying individual samples for 9 hours at 105°C, with a cooling-off period (overnight) after the first 5 hours of drying to prevent the fresh meat from hardening. Samples were allowed to cool, and the dry weight was recorded. The oven-dried sample was further dried for 3 hours at 105°C, then weighed. This procedure is repeated until the oven-dried meat weight becomes constant; the difference between the original and final oven-dried meat weights is the residual moisture content.

2.6 Data Analysis

The one-way analysis of variance with Duncan's Multiple Range Test at 95% confidence interval and pair-wise comparison of means and LSD using the *linear model*, genetic parameters, GAM, and Broad-sense heritability, which was estimated using the classical formula $H^2 = \sigma^2G / (\sigma^2G + \sigma^2E)$, where variance components were partitioned by one-way ANOVA using the *agricolae* and *variability* package, were all performed by RStudio v4.2. The standard selection intensity (i = 2.06, corresponding to a 5% selection proportion) was used for GAM: $i \times \sigma G / \mu \times 100$. OriginLab Pro 2024 v10.1 and Microsoft Excel 365 were used to generate the graphical representation of the data.

3. Results and Discussion

3.1 Phytochemical Compounds

The gallic acid equivalent (GAE μg/mL) of the phenolic content was observed to be higher in the Tagnanan tall population and lower in the Malayan dwarf population compared with the hybrid Matag (Table 1). The result revealed that the TPC was significantly and generally higher in the Tagnanan population (78.54±5.15), followed by the hybrid Matag population (62.2 ± 2.60) (Table 1). The result obtained in this study is higher than that previously reported by Ab Mutalib and Jailani [20] for tall coconut. However, it is lower than the result obtained by Keng et al. [21]. The maturity and age of fresh fruits significantly affect the TPC estimation [22]. All of these are due to the distinct genetic backgrounds of tall and dwarf palm types, which can influence the biosynthesis and accumulation of phenolic compounds. Also, hormonal changes and distinct phenolic profiles with varying levels of specific compounds during fruit development and ripening, which differ between dwarf and tall types, can influence phenol biosynthesis. The result also revealed an intermediate hybrid value between the parental populations and the hybrid in the measured phenolic concentration, suggestive of partial dominance (a formal mid-parent value analysis is recommended to confirm this classification). Coconuts exhibit increased phenolic content and antioxidant activity at maturity ages of up to 190 days after pollination, suggesting that the harvest time is also crucial for maximizing phenolic content [23]. The concentration and composition of phenolics in coconut vary greatly depending on the fruit part (mesocarp, testa, cotyledon, water) and maturity stage (young or mature). Notably, young coconut mesocarp extracts have demonstrated potent radical-scavenging activity, sometimes outperforming synthetic antioxidants such as butylhydroxytoluene (BHT) [24].

Table 1. Total phenolic and flavonoid contents and DPPH antioxidant activity

Population	TPC (mg GAE/g DW)	TFC (mg QE/g DW)	DPPH % inhibition
Tagnanan Tall	78.54 ± 2.95^{a}	91.83 ± 7.34 ^{a}	58.26 ± 1.00^{ab}
Malayan dwarf	54.10 ± 2.13^{c}	66.09 ± 1.03^{b}	58.97 ± 1.21^{a}
Hybrid Matag	62.20 ± 0.78^{b}	79.42 ± 7.93^{a}	57.06 ± 0.27^{b}

Data were expressed as mean ± SD (n=22). Letters a, b, and c in the same column are significantly different at the ($p<0.05$) level.

The total flavonoid content (TFC) results show that the Tagnanan population had the highest TFC (91.83±8.55), followed by the hybrid Matag population (79.42±9.27), as shown in Table 1. The graphical representation shows that the TFC in the Tagnanan population does not differ significantly from that in the hybrid Matag population (Table 1). This implies that the hybrid Matag population exhibited a total flavonoid content comparable to or exceeding that of the higher parent, suggesting dominance (a formal mid-parent heterosis analysis is recommended to confirm). The difference in flavonoid content between tall and hybrid coconut types can be attributed to genetic, environmental, and agronomic factors. Tall coconut types may have genetic traits that promote higher flavonoid accumulation, whereas hybrid types are bred for specific traits like yield or disease resistance, potentially reducing flavonoid content. Environmental factors, such as UV radiation, can stimulate flavonoid production in tall types, whereas controlled conditions in hybrids might reduce this effect. Additionally, differences in maturity stage, evolutionary adaptation, and metabolic pathways may also contribute to the variation in flavonoid content. These differences can impact the

nutritional and industrial value of coconut products. Higher flavonoid content in tall coconut types can enhance their antioxidant properties, potentially provide additional health benefits, and increase their value in pharmaceutical, food, and cosmetic industries. Understanding these differences can inform breeding programs to enhance flavonoid content in coconut varieties, ultimately leading to the development of more nutritious and valuable coconut products. These findings support the study by Arivalagan et al. [7], which revealed that tall and hybrid coconut meat has the highest flavonoid content compared with dwarf-type coconut meat. Flavonoids, as secondary metabolites with established health benefits, can help mitigate chronic diseases, primarily due to their antioxidant properties [20, 25]. These antioxidants are compounds that minimize the production of free radicals or interact with and neutralize them, potentially helping protect cells from oxidative damage [26]. Extraction methods also significantly affect flavonoid content in a sample, with optimized processes yielding up to 115 mg of quercetin equivalents per gram of defatted testa. This suggests that processing methods are crucial in maximizing the flavonoid content [7]. Phenolic and flavonoid compounds, including phenolic acids (like protocatechuic acid, chlorogenic acid, and vanillic acid), catechins, and epicatechins, are consistently reported as the primary contributors to radical scavenging activity in various coconut parts [27, 28]

The DPPH (2,2-diphenyl-1-picrylhydrazyl) assay measures the antioxidant activity of coconut meat by assessing the antioxidant's ability to neutralize the free radicals in the samples. The results of this experiment (Table 1) revealed that the highest per cent inhibition of antioxidants was observed in the parental materials Malayan dwarf and Tagnanan tall (58.97±1.99 and 58.26±1.93, respectively), which were not significantly different from the hybrid Matag. This indicates that the parental materials have a significant ability to scavenge DPPH free radicals and neutralize them [28, 29]. It also elucidates their potential for use in food products and cosmetics as natural antioxidants [30]. Arivalagan et al. [8] demonstrated that phenolic and flavonoid compounds in coconut meat significantly contribute to its DPPH scavenging activity, showing its potential as a natural source of antioxidants. The DPPH, a secondary plant metabolite, is primarily associated with health benefits, including anti-aging effects, the prevention of age-related diseases, anticancer properties, anti-inflammatory actions, and reduced risk of cardiovascular disease by protecting cells from free-radical damage [31].

3.2 Variability Estimates, Heritability, and Genetic Advance of Phenolic and Flavonoid Compounds and Their Antioxidant Activity

The phenotypic coefficient of variation (PCV) describes the variation in traits due to environmental and genetic factors. The results showed that TPC and TFC recorded PCV values of 26.46% and 23.28%, respectively, among the individuals assessed, with only 5.87% phenotypic variation for the DPPH (Table 2). This indicates low variation in the traits among individuals due to genetic and environmental factors, suggesting that inherited traits were either controlled by a few major genes or influenced by additive gene effects [11]. The TPC and TFC assays are more specific to certain types of compounds, which might exhibit higher variability due to genetic and environmental factors. DPPH assay measures the overall antioxidant activity, which is influenced by various compounds, including phenolics, flavonoids, and other antioxidants. The presence of multiple antioxidant compounds with varying potencies might reduce variability in the DPPH assay. The DPPH assay might not be as sensitive to specific phenolic compounds as the assays for TPC and TFC. This reduced sensitivity could lead to lower variability in the DPPH assay. The genetic control of antioxidant activity might be more complex than that of individual phenolic compounds. This complexity could lead to a more stable DPPH value across different genotypes or environments.

Table 2. Estimation of mean, variability, heritability, and genetic advance as a percentage of mean in phenolic and flavonoid compounds and antioxidant activity in coconut

Traits	Mean ± SE	PCV (%)	GCV (%)	h^2 (%)	GAM (%)
TPC	67.42 ± 3.24	26.46	25.12	90.13	49.13
TFC	81.43 ± 4.37	23.28	21.35	84.09	40.33
DPPH	58.12 ± 1.11	5.87	4.85	68.26	8.25

Data were expressed as mean ± SE (n=22).
TFC = total flavonoid content; TPC = total phenolic content; PCV = phenotypic coefficient of variation; GCV = genotypic coefficient of variation; h^2 = Heritability; GAM = genetic advance as a percentage of the mean.

The phenotypic coefficient of variation describes the variation in traits due to environmental and genetic factors. The result showed that TPC and TFC recorded phenotypic coefficient of variation of 26.46% and 23.28%, respectively, among the individuals assessed, with only 5.87% phenotypic variation for the DPPH (Table 2). This indicates low variation in the traits among individuals, suggesting that these were either inherited traits controlled by a few major genes or influenced by additive gene effects [14]. Similarly, the genotypic variations recorded were 25.12%, 21.35%, and 4.85% for TPC, TFC, and DPPH, respectively. The highest heritability estimate was observed for total phenolic content (90.13%), followed by TFC (84.09%), and the lowest for DPPH (68.26%). The TPC and TFC demonstrated strong heritability along with a high genetic variation coefficient. Cornelius [32] revealed that combining the genotypic coefficient of variation with heritability estimates provides a more precise assessment of selection efficiency. The insignificant variation in TPC and TFC among fruits indicates that the environment had little influence on these traits, and the minimal difference between the phenotypic and genotypic coefficients of variation indicates that both phenotypic and genotypic factors drive trait variation. This is comparable to the findings of Meena et al. [13], who studied the genetic variability in fruit crops. The genetic advancement as a percentage of the mean showed that TPC and TFC had predicted genetic gains of 49.13% and 40.33%, respectively, after selection, with a predicted genetic gain of 8.25% for DPPH scavenging activity (Table 2), thereby neutralizing free radicals during segregation selection. This elucidates that high heritability does not always accompany higher genetic advancement. It also explains that even though there may be less variation in the traits assessed, they have a greater capacity to duplicate these variations and improve genetic inheritance, which will assist researchers in selection for breeding programs. These combinations of genetic parameters may be due to non-additive gene action governing these traits [13].

3.3 Physicochemical Properties

The quality parameters of coconut fruits are mainly determined by their physical properties. The results of the physicochemical analysis revealed that there were no significant differences between the populations, with hybrid Matag and Malayan dwarf populations having the highest protein contents, 16.77% and 16.47%, respectively (Figure 1). However, the Tagnanan population had slightly lower protein content (14.12%) compared to the dwarf and hybrid Matag populations. The findings align with those of Maskromo et al. [28] on the dwarf population, which found that fruit protein content decreases as it matures. The sample population in this study of mature individuals has low protein content. The highest texture punching force (Figure 2) was observed for the meat of the hybrid Matag population with 109.91 ± 0.33 N, followed by the Tagnanan tall population with 85.87±0.27 N. The fruit texture analysis shows that there was a significant difference in the fruit mesocarp "hard" among the populations. The texture was expressed as Newton (N) from a conversion of pressure in (kg). The force and energy required to penetrate and remove coconut meat increased with the coconut's maturity. Immature coconuts typically yield soft, gelatinous meat with a mild flavor that can be easily scooped from the shell with a spoon. In contrast, mature coconuts exhibit much firmer, sweeter meat that adheres more rigidly to the shell, necessitating greater effort for extraction [27]. With limited literature on the physicochemical properties of Tagnanan and hybrid Matag, researchers have observed that the dwarf variety is highly regarded for its flavor, sweetness, and texture, surpassing both hybrid and tall varieties in these attributes [20]. This study reports, for the first time, a notably firmer and more rigid texture

in the hybrid Matag, a product of the cross between Tagnanan tall and Malayan dwarf. Total soluble solids in coconut can serve as a reliable indicator of its sweetness level [33].

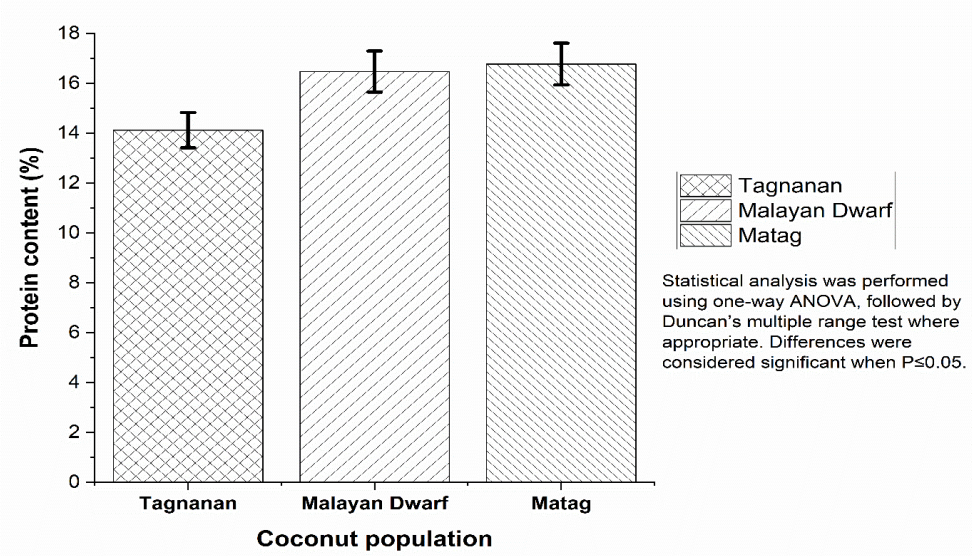


Figure 1. Protein content (%) of coconut fruit meat across three populations — hybrid Matag, Malayan dwarf, and Tagnanan tall — showing variation among genotypes. Values are mean ± SE (n=22).

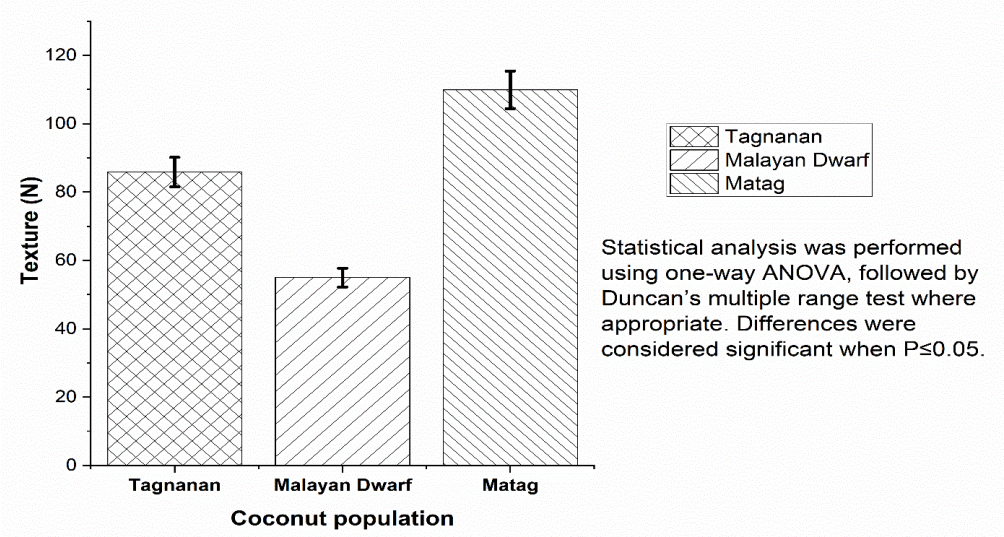


Figure 2. Fruit mesocarp texture (punching force, N) of coconut meat across hybrid Matag, Tagnanan tall, and Malayan dwarf populations. Values are mean ± SE (n=22).

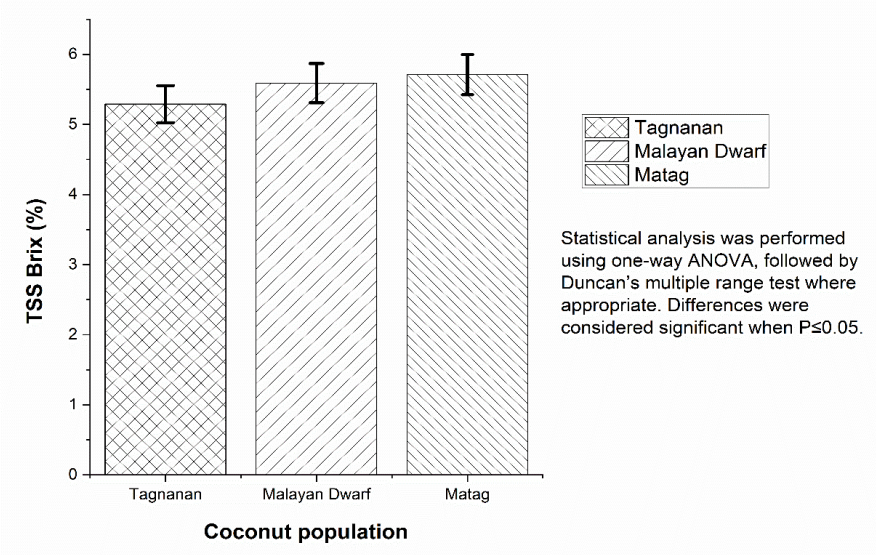


Figure 3. Total soluble solids (TSS, °Brix) of coconut water across hybrid Matag, Tagnanan tall, and Malayan dwarf populations as an indicator of sweetness. Values are mean ± SE (n=22).

The total soluble solids (TSS, Brixº) in coconuts can serve as a reliable indicator of their sweetness [34]. The TSS showed significant differences among all the populations, with values measured from the hybrid Matag (5.71%) higher than its parental materials (Figure 3). A study confirmed that coconut contains 5–8% total soluble solids, with trace amounts of amino acids, organic acids, and minerals [23]. These current findings are slightly lower than those reported by Halim et al. [35]. However, it emphasizes that this could be affected by the coconut's harvesting time, typically at 12 months, which slightly reduces TSS content thereafter. There was a significant difference in fruit pH among the populations; all were slightly acidic. Notably, the Malayan dwarf coconut population tended to have higher pH values, followed by the hybrid Matag population (Figure 4). The findings of Ab Mutalib and Jailani [20] revealed higher pH values for hybrid Matag, dwarf pandan, and Malayan tall, confirming this study. The maturity of the fruit determines the pH level; younger fruits are less acidic than mature fruits, which are acidic to neutral in the populations assessed. This agrees with the studies of Tan et al. [29] and Keng et al. [21], which state that younger fruits tend to be more acidic than mature fruits. The dry matter weight was higher in the Tagnanan population (Figure 5). The populations assessed also showed significant differences. This implied that the higher the dry matter content, the lower the moisture content [14]. This trend was also reported by Ibrahim et al. [30], who found that fruits with higher dry matter content tend to have longer shelf lives due to reduced water activity, which can inhibit microbial growth and spoilage. This relationship suggests that as the dry matter content increases, the fruit or plant material becomes drier, and conversely, as moisture content increases, the dry matter content decreases. This is consistent with the principle of conservation of mass, which states that the total mass of a system comprises both dry matter and moisture.

3.4 Mean, Variability, Heritability, and Genetic Advance as Percentage of Mean in Physicochemical Properties of Coconut Populations

Phenotypic coefficient variation revealed significant trait variability, indicating that both genetic and environmental factors contribute to the observed differences. The genotypic variances of all traits were lower than their phenotypic variances. Roy and Shil [32] have established that PCV and GCV measurements exceeding 20% are classified as high, values between 10% and 20% as medium, and values below 10% as low. These results indicated that protein content and fruit texture showed higher variations of 28.75% and 29.36%, respectively, followed by total soluble sugar with a medium variation of 11.61% and dry matter with a variation of 13.56%. However, pH showed the least variation among the individuals evaluated, at 6.12% (Table 3). These suggest relatively low variation in the measured traits, implying that both genetic and environmental factors contribute minimally to the observed differences. The data further imply that the genetic constitution of the fruits predominantly governs their quality, with environmental factors exerting

negligible influence on trait performance. Although there were significant limitations to the palm population selection, convenience sampling was based on the number of mature palms available, implying non-random convenience sampling.

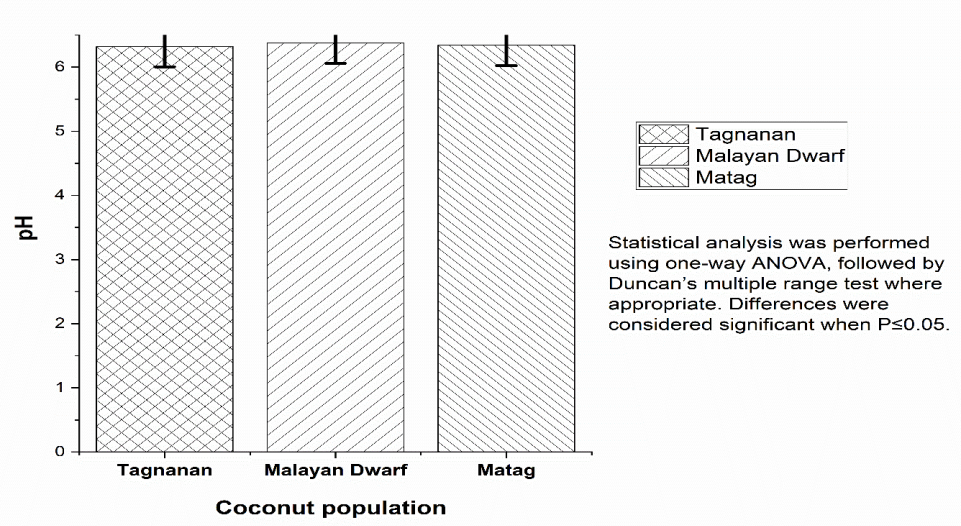


Figure 4. pH of coconut water across hybrid Matag, Tagnanan tall, and Malayan dwarf populations, reflecting fruit acidity at maturity. Values are mean ± SE (n=22).

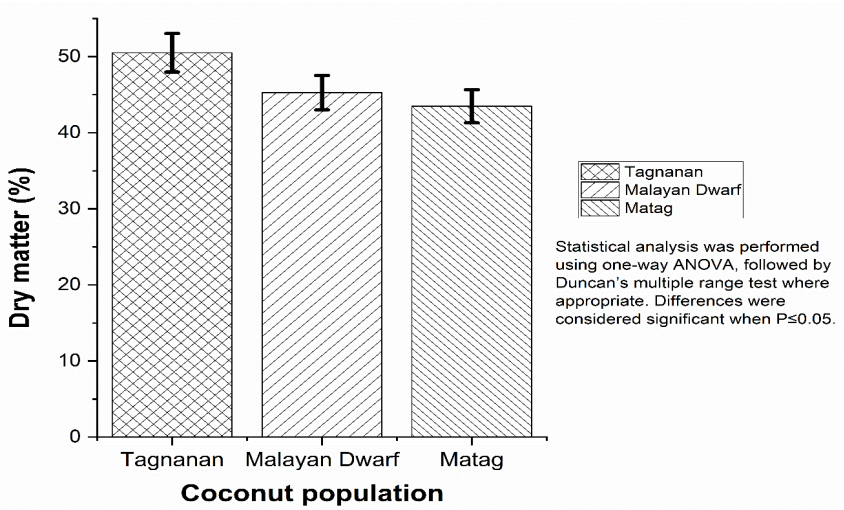


Figure 5. Fruit dry matter content **(%)** of coconut meat across hybrid Matag, Tagnanan tall, and Malayan dwarf populations, inversely reflecting moisture. Values are mean ± SE (n=22).

Table 3. Mean, Variability, Heritability, and Genetic Advance as a percentage of means in Physicochemical properties of Coconut populations

Traits	Mean ± SE	PCV %	GCV %	h^2 %	GAM %
Protein	15.48 ± 2.31	28.75	12.66	19.38	11.48
TSS ºBrix	5.49 ± 0.02	11.61	11.59	99.58	23.82
Texture	84.01 ± 0.53	29.36	29.34	99.86	60.39
pH	6.34 ± 0.03	6.12	6.08	98.67	12.43
DRM	47.16 ± 0.80	13.56	13.23	95.25	26.61

Data were expressed as mean ± SE (n=22).

PCV = phenotypic coefficient of variation; GCV = genotypic coefficient of variation; h^2 = Heritability; GAM = genetic advance as a percentage of the mean; TSS = total soluble solids; DRM = dry matter

The study on genetic variability also revealed that traits such as dry matter and total soluble solids were predominantly influenced by genotypic factors, as indicated by the close correspondence between GCV and PCV, making these traits promising for selection. Significant genetic improvement was observed in protein content and total soluble solids, indicating that these traits can be enhanced through selective breeding [36]. High heritability and genetic advance were observed for traits like protein content, which are largely governed by additive genetic effects and can be targeted for breeding programs [37]. In another study, high PCV, GCV, and genetic advances were recorded for dry matter content and TSS, suggesting significant scope for improvement in these traits [10]. The variation in the measured traits indicates they are largely unaffected by environmental factors, and the small difference between PCV and GCV suggests that both phenotypic and genotypic factors contribute to the observed variability. PCV values exceeded GCV values across all traits, suggesting a significant environmental impact on trait expression. Similar findings by Dangi et al. [9] revealed that PCV values are higher than GCV values for most traits measured, suggesting that environmental factors influence trait expression and contribute to increased variability.

Heritability estimates for these populations revealed that fruit texture and TSS had the highest heritability, at 99.86% and 99.58%, respectively, followed by pH (98.67%) and dry matter content (95.25%). The protein content, however, showed very low heritability (19.38%). The high heritability of fruit texture, TSS, pH, and dry matter content suggests that nearly all observed variations in these traits are due to genetic differences rather than environmental factors. This means that selective breeding for these traits would likely be highly effective, as they are strongly inherited from one generation to the next. It also indicates that the phenotypic variation is primarily controlled by genetic factors, making these traits good candidates for genetic improvement through breeding programs. These findings align with the study by Kumar et al. [25], which demonstrates that traits with strong genetic control can be effectively improved through selection and breeding because the genetic factors underlying these traits are more stable and heritable. They further clarified that high heritability estimates indicate that a large portion of the variation is due to genetic differences and that selection for the trait should be effective.

On the other hand, the low heritability of protein suggests that this trait is heavily influenced by environmental factors or possibly by non-additive genetic effects such as dominance and epistasis. This aligns with findings in various crops where protein content has been shown to exhibit significant environmental variation, making it a more complex trait to improve through breeding alone [18, 33]. High heritability does not inherently guarantee a high genetic advance. The percentage of genetic advancement of the mean indicated a predicted genetic gain of 60.39% for fruit texture, with dry matter and total soluble sugar recording 26.61% and 23.82%, respectively. The pH has consistently shown low variation and low genetic gain prediction amongst the measured traits, with only 12.43%. These results indicate that, despite the low variation observed in the assessed traits, there is a significant potential for these traits to increase the variability and enhance genetic inheritance.

4. Conclusions

The phytochemical study highlights the potential of coconut fruits as a source of natural antioxidants, with both genetic factors and harvesting time influencing their phenolic and flavonoid content and antioxidant activity. Phytochemical compounds can neutralize free radicals, potentially protecting cells from oxidative damage. Furthermore, processing methods are crucial for maximizing flavonoid content. It also highlights the potential of both parental populations, with their antioxidant activity comparable to, and potentially superior to, that of the hybrid Matag population. The phenotypic and genotypic coefficient of variations in TPC and TFC show a low variation of the traits among individuals in terms of genetic and environmental factors, coupled with high heritability, showing that these traits were either inherited characteristics regulated by a limited number of major genes or influenced by additive gene effects, with their scavenging activities showing a very low variation among the traits measured. This clarifies the effectiveness of selection: despite limited variation within traits, existing variation can be leveraged to replicate and enhance desirable genetic traits, ultimately improving inheritance. Physicochemical analysis revealed that hybrid Matag and Malayan dwarf populations have the highest protein content. The highest punching force was observed for the meat of hybrid Matag, and the TSS of coconut meat obtained from hybrid Matag was higher than that of its parental materials.

There was also a high coefficient of variation in protein content and the fruit texture. The genetic constitution of the fruits predominantly governs their quality, with environmental factors exerting negligible influence on trait performance. Significant genetic gains were observed in protein content and TSS, suggesting that these traits can be improved through selection. High heritability was observed for all measured traits except protein content, and PCV was higher than GCV for all traits. The percentage of genetic advancement of the mean indicated predicted genetic gains for fruit texture, dry matter, and TSS, revealing significant potential for these traits to increase variability and enhance genetic inheritance. The overall findings show significant variability among the traits studied, with promising phytochemical and physicochemical profiles that warrant further investigation in multi-location trials. These findings provide valuable information for coconut breeding programs and the development of new coconut varieties with desirable traits.

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References

[1] Sankaran, M.; Damodaran, V.; Singh, D. R.; Jerard, B. A.; Joseph, S. Characterization and Diversity Assessment in Coconut Collections of Pacific Ocean Islands and Nicobar Islands. *Afr. J. Biotechnol.* **2012**, *11*, 16320–16329. https://doi.org/10.5897/AJB12.2742

[2] Geethanjali, S.; Rajkumar, D.; Shoba, N. Correlation and Path Coefficient Analysis in Coconut (*Cocos nucifera* L.). *Electron. J. Plant Breed.* **2014**, *5*, 702–707.

[3] Lebrun, P.; Berger, A.; Hodgkin, T.; Baudouin, L. Biochemical and Molecular Methods for Characterizing Coconut Diversity. In *Coconut Genetic Resources*; 2005; pp 225–245.

[4] Sudha, R.; Niral, V. Novel Traits in Coconut (*Cocos nucifera* L.) Palms. *Vigyan Varta Int. E-Mag. Sci. Enthusiasts* **2021**, *2*, 41–45.

[5] Shayanthavi, S.; Kapilan, R.; Wickramasinghe, I. Comprehensive Analysis of Physicochemical, Nutritional, and Antioxidant Properties of Various Forms and Varieties of Tender Coconut (*Cocos nucifera* L.) Water in Northern Sri Lanka. *Food Chem. Adv.* **2024**, *4*, 100645. https://doi.org/10.1016/j.focha.2024.100645

[6] Jain, S.; Srivastava, S. C.; Singh, S. K.; Indapurkar, Y. M.; Singh, B. K. Studies on Genetic Variability, Character Association and Path Analysis for Yield and Its Contributing Traits in Soybean [*Glycine max* (L.) Merrill]. *Legume Res.* **2015**, *38*, 182–184. https://doi.org/10.5958/0976-0571.2015.00031.4

[7] Plongbunjong, V.; Suhem, K.; Kanjanarong, J. Development of Probiotic Soy Yogurt Containing Kale Powder: Evaluation of Functional and Plant-Based Properties. *ASEAN J. Sci. Tech. Report* **2026**, *29*, 260295. https://doi.org/10.55164/ajstr.v29i2.260295

[8] Arivalagan, M.; Roy, T. K.; Yasmeen, A. M.; Pavithra, K. C.; Jwala, P. N.; Manikantan, M. R.; Hebbar, K. B.; Kanade, S. R. Genotype Influences on the Coconut (*Cocos nucifera* L.) Meat Nutrients and Fatty Acids. *LWT Food Sci. Technol.* **2018**. https://doi.org/10.1016/j.lwt.2018.02.024

[9] Rivera, A.; Mallor, C.; Garcés-Claver, A.; García-Ulloa, A.; Pomar, F.; Silvar, C. Assessing the Genetic Diversity in Onion (*Allium cepa* L.) Landraces from Northwest Spain and Comparison with the European Variability. *N. Z. J. Crop Hortic. Sci.* **2016**, *44*, 103–120. https://doi.org/10.1080/01140671.2016.1150308

[10] Dangi, R.; Kumar, A.; Khar, A. Genetic Variability, Heritability, and Diversity Analysis in Short Day Tropical Onion (*Allium cepa*). *Indian J. Agric. Sci.* **2018**, *88*, 948–957. https://doi.org/10.56093/ijas.v88i6.80653

[11] Singh, Y.; Sharma, M.; Sharma, A. Genetic Variation, Association of Characters, and Their Direct and Indirect Contributions for Improvement in Chilli Peppers. *Int. J. Veg. Sci.* **2009**, *15*, 340–368. https://doi.org/10.1080/19315260903004158

[12] Zizumbo-Villarreal, D.; Fernández-Barrera, M.; Torres-Hernández, N.; Colunga-GarcíaMarín, P. Morphological Variation of Fruit in Mexican Populations of *Cocos nucifera* L. (Arecaceae) under *In Situ* and *Ex Situ* Conditions. *Genet. Resour. Crop Evol.* **2005**, *52*, 421–434. https://doi.org/10.1007/s10722-005-2253-1

[13] Meena, V. S.; Singh, K.; Shekhawat, N.; Bhardwaj, R.; Lal, H.; Rani, K.; Gupta, V.; Kumar, A.; Singh, A.; Gora, J. S.; Kumar, P. Assessment of Genetic Variability for Fruit Nutritional Composition in the *Ex Situ* Collection of Jujube (*Ziziphus* spp.) Genotypes of Arid Regions of India. *Horticulturae* **2023**, *9*, 0210. https://doi.org/10.3390/horticulturae9020210

[14] Lal, S.; Singh, D. Genetic Divergence among 22 Strawberry (*Fragaria* × *ananassa* Duch.) Genotypes for Bioactive Compounds Grown in Northwest Himalayas. *SAARC J. Agric.* **2016**, *14*, 81–91. https://doi.org/10.3329/sja.v14i1.29578

[15] Patel, U. V.; Parmar, V. K.; Tandel, Y. N.; Patel, H. R. Genetic Divergence in Cowpea [*Vigna unguiculata* (L.) Walp.] for Yield Components Parameters. *Electron. J. Plant Breed.* **2017**, *8*, 331–335. https://doi.org/10.5958/0975-928X.2017.00049.7

[16] Gutfinger, T. Polyphenols in Olive Oils. *J. Am. Oil Chem. Soc.* **1981**, *58*, 966–968. https://doi.org/10.1007/BF02659771

[17] Zhishen, J.; Mengcheng, T.; Jianming, W. The Determination of Flavonoid Contents in Mulberry and Their Scavenging Effects on Superoxide Radicals. *Food Chem.* **1999**, *64*, 555–559. https://doi.org/10.1016/S0308-8146(98)00102-2

[18] Houle, D. Comparing Evolvability and Variability. *Genetics* **1992**, *130*, 195–204.

[19] Kaewseejan, N.; Siriamornpun, S. Bioactive Components and Properties of Ethanolic Extract and Its Fractions from *Gynura procumbens* Leaves. *Ind. Crops Prod.* **2015**, *74*, 271–278.

[20] Sukkaew, A.; Phasuk, S.; Takolpuckdee, P. Synthesis and Characterization of Carboxymethyl Cellulose from Sugarcane Bagasse Cellulose Using Physical and Chemical Pretreatments. *ASEAN J. Sci. Tech. Report* **2026**, *29*, 261176. https://doi.org/10.55164/ajstr.v29i5.261176

[21] Brand-Williams, W.; Cuvelier, M. E.; Berset, C. L. W. T. Use of a Free Radical Method to Evaluate Antioxidant Activity. *LWT Food Sci. Technol.* **1995**, *28*, 25–30. https://doi.org/10.1016/S0023-6438(95)80008-5

[22] Kiran, T. N.; Bhuvaneswari, G.; Reddisekhar, M.; Sunil, N.; Vanisri, S. Genetic Variability, Heritability, and Genetic Advance for Grain Quality Traits in Rice. *Int. J. Curr. Microbiol. Appl. Sci.* **2017**, *6*, 1996–2001.

[23] Ab Mutalib, S. R.; Jailani, F. Physicochemical Properties and Sensory Acceptability of Different Varieties of Coconut Water and Flesh. *Sci. Res. J.* **2022**, *19*, 75. https://doi.org/10.24191/srj.v19i1.13793

[24] Keng, S. E.; Mat Easa, A.; Munir, A.; Muhamed, C.; Ooi, C.-H.; Chew, T. T. Composition and Physicochemical Properties of Fresh and Freeze-Concentrated Coconut (*Cocos nucifera* L.) Water. *J. Agrobiotech.* **2017**, *8*, 13–24.

[25] Kumar, S.; Molloy, C.; Muñoz, P.; Daetwyler, H.; Chagné, D.; Volz, R. Genome-Enabled Estimates of Additive and Nonadditive Genetic Variances and Prediction of Apple Phenotypes across Environments. *G3 Genes Genomes Genet.* **2015**, *5*, 2711–2718. https://doi.org/10.1534/g3.115.021105

[26] Alburo, R. P.; Villegas, L. M. G. Ecological Risk Assessment of Heavy Metal Pollution in Surface Water and Sediment of Lahug River, Cebu, Philippines. *ASEAN J. Sci. Tech. Report* **2025**, *28*, 257492. https://doi.org/10.55164/ajstr.v28i3.257492

[27] Mahayothee, B.; Koomyart, I.; Khuwijitjaru, P.; Siriwongwilaichat, P.; Nagle, M.; Müller, J. Phenolic Compounds, Antioxidant Activity, and Medium-Chain Fatty Acids Profiles of Coconut Water and

Meat at Different Maturity Stages. *Int. J. Food Prop.* **2016**, *19*, 2041–2051. https://doi.org/10.1080/10942912.2015.1099042

[28] Kalina, S.; Navaratne, S. B. Analysis of Antioxidant Activity and Texture Profile of Tender-Young and King Coconut (*Cocos nucifera* L.) Mesocarps under Different Treatments and the Possibility to Develop a Food Product. *Int. J. Food Sci.* **2019**, 7470696. https://doi.org/10.1155/2019/7470696

[29] Gu, C.; Howell, K.; Dunshea, F. R.; Suleria, H. A. R. LC-ESI-QTOF/MS Characterisation of Phenolic Acids and Flavonoids in Polyphenol-Rich Fruits and Vegetables and Their Potential Antioxidant Activities. *Antioxidants* **2019**, *8*, 405. https://doi.org/10.3390/antiox8090405

[30] Irawan, J.; Hakim, A.; Hadisaputra, S. Free Radical Scavenging Actions of Virgin Coconut Oil. *Acta Chim. Asiana* **2022**, *5*, 202–207. https://doi.org/10.29303/aca.v5i2.120

[31] Leliana, L.; Setyaningsih, W.; Palma, M.; Supriyadi; Santoso, U. Antioxidant Activity of Aqueous and Ethanolic Extracts of Coconut (*Cocos nucifera* L.) Fruit By-Products. *Agronomy* **2022**, *12*, 1102. https://doi.org/10.3390/agronomy12051102

[32] Cornelius, J. P. Heritabilities and Additive Genetic Coefficients of Variation in Forest Trees. *Can. J. For. Res.* **1994**, *24*, 372–379. https://doi.org/10.1139/x94-050

[33] Visscher, P. M.; Hill, W. G.; Wray, N. R. Heritability in the Genomics Era—Concepts and Misconceptions. *Nat. Rev. Genet.* **2008**, *9*, 255–266. https://doi.org/10.1038/nrg2322

[34] Arcales-Quinal, J. A.; Inolino, R. Physicochemical Properties of Carrageenan Extracted from Raw Dried Seaweed of Caluya, Antique, Philippines. *ASEAN J. Sci. Tech. Report* **2026**, *29*, 259655. https://doi.org/10.55164/ajstr.v29i3.259655

[35] Giang, N. T. N.; Van, K. T.; Ha, H. T. N. The Combination of Different Carriers in Producing Plant-Based Seasoning Powder from Oyster Mushroom (*Pleurotus sajor-caju*). *ASEAN J. Sci. Tech. Report* **2026**, *29*, 261864. https://doi.org/10.55164/ajstr.v29i3.261864

[36] Maskromo, I.; Karouw, S.; Pandin, D. S.; Mahayu, W. M.; Santosa, B.; Alouw, J. C. Physicochemical Properties of Kebumen Entog Dwarf Coconut. *IOP Conf. Ser.: Earth Environ. Sci.* **2020**, *418*, 012037. https://doi.org/10.1088/1755-1315/418/1/012037

[37] Theerathammakorn, S.; Dittakit, P.; Koopipat, C. Sweetness and Antioxidant Indices of Mango (*Mangifera indica* cv. Nam Dok Mai Sithong) Using RGB and Near-Infrared Images. *ASEAN J. Sci. Tech. Report* **2026**, *29*, 261814. https://doi.org/10.55164/ajstr.v29i5.261814