

Diversity pattern on phytochemical traits of coffee bean skin from various species and harvesting methods

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ABSTRACT

Coffee is a well-known beverage consumed widely all around the globe. During its processing, a vast amount of waste was generated that can be utilized due to its bioactive compounds beneficial for human health. This study aimed to investigate the diversity pattern of three coffee pulp species based on phytochemical properties (total phenolic content (TPC), caffeine content, and antioxidant activity using the DPPH assay) exhibited by the skin of three coffee bean species: *Coffea arabica* (Arabica), *Coffea canephora* (Robusta), and *Coffea liberica* (Liberica) harvested with different technique (selective and strip picking). This study revealed that species and harvesting techniques significantly influenced the phytochemical properties of the coffee bean skin (CBS). The diversity pattern is shown by Principal Component Analysis (PCA), which has a correlation between Robusta and TPC and Arabica with Caffeine content. According to the result, the diversity pattern of coffee bean skin is more influenced by species than by harvesting method because each species has a high determinant on the phytochemical composition. The findings from this study suggest the possibility of utilizing the waste from the coffee industry, especially the skin, to be used further in the development of products with considerable amounts of bioactive compounds.

Key words: Coffee bean skin; phytochemicals; principal component analysis; selective picking; strip picking.

1 INTRODUCTION

Coffee industries generate over \$200 billion in revenue annually due to its widespread consumption as one of the most popular non-alcoholic beverages globally (Abdelwareth; Zayed; Farag, 2021; Da Silva et al., 2022). Coffee is well-known for its flavor, but it also has a wide range of chemical components, such as flavonoids, phenolic acids, terpenoids, and alkaloids (Socala et al., 2021). This product, which has benefits such as decreasing blood sugar, shielding the liver and nerves, and acting as an antioxidant, is among the most significant commodities on the global market (Saad; Salamattullah, 2021).

Indonesia boasts a geographical advantage that greatly promotes the growth and development of coffee, making it one of the globe's biggest and best coffee-producing nations with a diverse variety of coffee (Maxiselly et al., 2023a). According to Patay et al. (2016), the three most well-known coffee species in the world for coffee products are *Coffea arabica*, *Coffea canephora*, and *Coffea liberica*; each has advantages and disadvantages. Arabica is less caffeinated, has a pleasant flavor and scent, and is susceptible to some coffee-related illnesses. As opposed to Arabica, which is more resistant to disease, *Coffea canephora*, often known as Robusta, is of lesser quality and has a higher caffeine content (Mathur et al., 2014; Maxiselly et al., 2023b). However, *C. liberica*, a native of Africa, has larger fruit but a more intensely bitter flavor than

other varieties (Britta, 2017). This species has a huge amount of pulp due to its large fruit size, is resistant to drought, and has a very broad range of variations (Davis et al., 2022).

Phytochemical characteristics are among the traits used in the coffee business to evaluate the quality of beans. These traits will differ based on their environment, genetic makeup, production method (from seedling to harvest), and post-harvest handling (Vionita; Kardhinata; Damanik, 2021). Coffee farmers often harvest using two methods: strip (mixed maturity phase) and selective (ripe fruit exclusively) picking. The ripe coffee cherries are said to have good morpho-physiological and phytochemical contents when they are in good condition. However, the method of stripping coffee cherries results in a variety of coffee cherries that are not fully ripe, including red, yellow, and green (Maxiselly et al., 2023b).

A portion of coffee beans are utilized by the beverage sector, while the remaining portion is discarded. Coffee fruit consists of skin, pulp, parchment, silver skin and beans, while only the beans are processed into coffee products (Mussatto et al., 2011). Approximately half of coffee cherries are lost during the processing of coffee beans, according to studies by Gouvea et al. (2009) and Orrego, Zapata-Zapata and Kim (2018). Furthermore, it was stated that 1 kg of coffee beans would yield 1 kg of trash (43.2% skin and pulp, 6.1% parchment, and 11.8% mucilage and soluble sugar) after processing. Recently, coffee waste has been put to use for a variety of things, including tea, animal feed, organic

fertilizers, and as a starting point for the creation of biofuel (Echeverria; Nuti, 2017). However, coffee waste includes the skin of the coffee bean and contains valuable secondary metabolites including phenolic chemicals and caffeine (Al-Yousef; Amina, 2018; Carmen et al., 2020).

Based on the aforementioned background, the objectives of this study were to investigate some phytochemical properties from the skin of three coffee beans species and analyze the correlation between species, harvesting technique, and phytochemical properties of the coffee bean skin (CBS).

2 MATERIAL AND METHODS

2.1 Study area

The research was conducted at the Faculty of Agriculture, Universitas Padjadjaran, Jatinangor, Sumedang Regency from January to May 2023.

2.2 Materials

The Robusta coffee was taken from Lampung Province, Indonesia (5.379891°S 105.095987°E) at an elevation of 500 m above sea level, a temperature around 29–30 °C and a humidity of 67–85%, whereas the Arabica and Liberica were taken from West Java Province, Indonesia 7.58190°S 107.360020°E). The coffee sample were harvested using 2 methods: selective (ripe only) and strip (mixed maturity fruits) picking technique. Six kilograms were produced for each method, with a total of 12 kg of coffee cherries. After harvesting, the coffee cherries were soaked in water for 2 h to sort and separate the cherries from dirt, pests, and hollow cherries that were carried away from the harvesting process, and peeled with a pulper machine (VKT-200, VOS Machinery Equipment Co., Ltd., Zhengzhou, China). The skin was separated from the pulp and dried using an oven at 50 °C for 48 h (Maxiselly et al., 2023b). The main observations of the CBS were the total phenolic content, caffeine content, and antioxidant activity using the DPPH assay.

2.3 Procedures

The preparation of the sample for the phytochemicals properties analysis was conducted following the method described by Maxiselly et al. (2023b). The dried CBS was milled using a coffee grinder (Sf 3526, Sonifer, Yiwu, China) prior to the extraction using distilled water for 24 h (25 mg/mL). The solution was filtered using Whatman filter paper No. 1, stored in an amber bottle and kept in the refrigerator at 4 °C until further use.

2.4 Total Phenolic Content

The TPC of the CBS was determined using the Folin-Ciocalteu method. The methanolic extract (400

μL) was mixed with Folin-Ciocalteu phenol reagent (2 mL) and 7% Na₂CO₃ (1.6 mL). The mixed solution was allowed to stand for 45 min in the dark. The absorbance of the solution was measured at 765 nm and the result was reported as mg of gallic acid equivalent (GAE)/g (Renaldi et al., 2022).

2.5 Caffeine content

The separation of caffeine by adsorption technique was completed according to the method described by Maxiselly et al. (2023b). The sample (15 mL) was put into a 250 mL Erlenmeyer flask and activated carbon (0.15 g) was added. The mixture was stirred briefly, allowed to stand for 5 min and then filtered using Whatman filter paper No. 1 for 10 min. The filtrate obtained was diluted to the mark with distilled water in a 100 mL volumetric flask. The absorbance of the solution was measured using a spectrophotometer at 400 nm.

2.6 DPPH assay

A solution consisting of DPPH (2.4 mg) in methanol (100 mL) was prepared for the DPPH radical scavenging assay. The DPPH radical scavenging activity was measured by mixing the extract (150 μL) with the methanolic DPPH (3.85 mL) and allowing it to stand in the dark for 30 min. The absorbance was immediately measured at 517 nm. The absorbance value was measured using a spectrophotometer (Biochrom Libra S22, Biochrom, UK). The results on all assays were reported as mg trolox equivalent (TE)/g (Renaldi et al., 2022).

2.7 Data analysis

The mean values and standard deviations were used to present the data, and all analyses were conducted in triplicate. Using SPSS software version 17 (SPSS Inc., Chicago, IL, USA), the statistical analysis was carried out. The significance level at the 95% confidence limit was determined by applying Duncan's Multiple Range Test (DMRT). Analyses of the relationship among coffee species phytochemical contents was done by using the principal components analysis (PCA), and the trait data were graphically analyzed across the three species. The PCA biplots were made by XLSTAT to examine the association and opposition between phytochemical contents and species variation on a multivariate scale.

3 RESULTS

3.1 Phytochemical Properties of CBS

The TPC of the CBS harvested with selective picking was in the range of 3.70-5.70 mg GAE/g sample,

significantly lower than the CBS harvested with strip picking technique (7.96-12.72 mg GAE/g sample) (Table 1). The selectively picked *Coffea arabica* shown the highest TPC value (5.70 ± 0.01 mg GAE/g sample), while strip picking method resulting in *C. arabica* with the lowest TPC value (7.96 ± 0.01 mg GAE/g sample). Conversely, selective picking method resulting in *C. canephora* with the lowest TPC value (3.70 ± 0.01 mg GAE/g sample) and the strip picking method resulting in *C. canephora* with the highest TPC value (12.72 ± 0.01 mg GAE/g sample).

The result showed that selective and strip picking method resulting in CBS with caffeine content in the range of 18.31-87.29 mg/100 g sample and 18.81-76.19 mg/100 g sample, respectively (Table 1). The harvesting method significantly affected the caffeine content of the CBS, and the caffeine content was significantly different between coffee species. For both harvesting method, *C. canephora* exhibited the lowest caffeine content (18.31-18.81 mg/100 g sample), and the highest caffeine content was shown in the *C. arabica* sample (76.19-87.29 mg/100 g sample).

In the present study, the 1,1-Diphenyl-2-picrylhydrazyl (DPPH) radical scavenging capacity assays was used due to its high degree of sensitivity, reproducibility and repeatability of these methods (Šamec et al., 2016). It was revealed that for selective and strip picking method, *C. liberica* possessed the lowest DPPH value (17.66-18.33 mg GAE/g sample) compared to *C. arabica* (44.49-44.70 mg GAE/g sample) and *C. canephora* (46.08-47.60 mg GAE/g sample), as shown in Table 1.

3.2 Diversity pattern of phytochemical traits from the three coffee bean skin species based on Principal Component Analysis (PCA)

The measurement results show that only PC1 shows an eigenvalue >1 with a variation value of 40.29%, as shown in Table 2. When the outcome is greater than or equal to one, the eigenvalues in the main component (PC) can explain the variety and the cumulative factor (Maulana et al., 2023). In order to emphasize the similarity and dissimilarity among the coffee species, PCA analysis result is presented in Figure

1. PCA biplots generated from the first two PCs were used to identify the relationship between the phytochemical properties and the coffee species analyzed. The first two principal components (PC) accounted for 73.20% of the variation among the three coffee species. PCA measurements for the diversity of coffee species tested showed a variation of the first component (PC1) of 40.29%, with all traits showing the maximum contribution. In the second component (PC2), the variation contribution is 32.92%. The traits that influenced diversity in PC1 were polyphenol and caffeine contents while antioxidant activity contributed in PC2. The contribution is shown by the value in Table 3 which has a value of more than 0.5 (Maulana et al., 2023).

4 DISCUSSION

Based on the findings in this study, the harvesting method significantly affected the phytochemical properties of the CBS, and the caffeine content was significantly different between coffee species. Bioactive compounds are naturally occurring metabolites that exhibit a variety of structural and chemical properties. They are extensively found throughout the plant kingdom and offer numerous advantages. Food and pharmaceutical companies have shown a great deal of interest in phenolic compounds in particular due to their potential for numerous health benefits (Chiva-Blanch; Visioli, 2012; Giampieri et al., 2015; Salar; Purewal; Sandhu, 2017). Furthermore, many plant species, such as coffee, tea, and cocoa, naturally contain caffeine as an alkaloid in their leaves, seeds, and fruits (Bhawani; Fong; Ibrahim, 2015; Da Silva et al., 2018; Carmen et al., 2020; Quintero-Jaramillo et al., 2021). Nevertheless, studies on antioxidants found in plants and foods have become one of the most popular subjects in the field of food and agriculture research due to mounting evidence that oxidative stress brought on by free radicals plays a role in the development of numerous diseases (Takashima et al., 2012). By obstructing or delaying unfavorable oxidation events, antioxidants decrease oxidative stress, which is linked to diseases like cancer, neurological disorders, and high blood pressure (Apak, 2019).

Table 1: Phytochemical properties of Coffee Bean Skin (CBS) species with various harvesting method.

CBS	TPC (mg GAE/g sample)			Caffeine (mg/ 100 g sample)			DPPH (mg TE/g sample)		
	Arabica	Robusta	Liberica	Arabica	Robusta	Liberica	Arabica	Robusta	Liberica
Selective picking	5.70 ± 0.01^{Ba}	3.70 ± 0.01^{Bc}	5.60 ± 0.01^{Bb}	87.29 ± 0.08^{Aa}	18.31 ± 0.03^{Bc}	41.72 ± 3.44^{Bb}	44.49 ± 0.78^{Bb}	47.60 ± 0.11^{Aa}	18.33 ± 0.04^{Ac}
Strip picking	7.96 ± 0.01^{Ac}	12.72 ± 0.01^{Aa}	9.78 ± 0.01^{Ab}	76.19 ± 0.01^{Ba}	18.81 ± 2.20^{Ac}	48.02 ± 0.01^{Ab}	44.70 ± 0.38^{Ab}	46.08 ± 0.03^{Ba}	17.66 ± 0.01^{Bc}

Note: Data was presented as mean SD; TPC = total phenolic content; GAE = gallic acid equivalent; TE = trolox equivalent. Different uppercase superscript letter means significant ($p < 0.05$) difference between harvesting technique; Different lowercase superscript letter means significant ($p < 0.05$) difference between species.

In selective picking method, the collected samples were only the ripe fruit, whereas in strip picking method, coffee bean with mixed maturities were collected. According to Alam, Warkoyo and Siskawardani (2023), the amount of chemical components, including caffeine, phytochemicals, and other minerals, can vary depending on the maturation degree of the beans. When coffee fruits reach maturity, their levels of phenolic chemicals decrease (Velásquez; Banchón, 2023). This might explain the significantly lower values of some phytochemical properties of the samples collected using the selective picking method. Young coffee leaves showed greater total phenolic compounds than mature leaves, much like coffee beans do (Ngamsuk et al., 2019). However, some of the results showed higher values of phytochemical content exhibited by the samples with selective picking. These

Table 2: Eigenvalue, variance, and cumulative of phytochemical trait on CBS.

	Principal Component (PC)		
	1	2	3
Eigenvalue	1.21	0.99	0.80
Variance (%)	40.29	32.92	26.80
Cumulative	40.29	73.20	100.00

Table 3: Trait values influencing the diversity of CBS.

	PC1	PC2	PC3
Polyphenol	0.580	0.010	0.410
Caffeine	0.548	0.069	0.384
Antioxidant	0.081	0.909	0.010

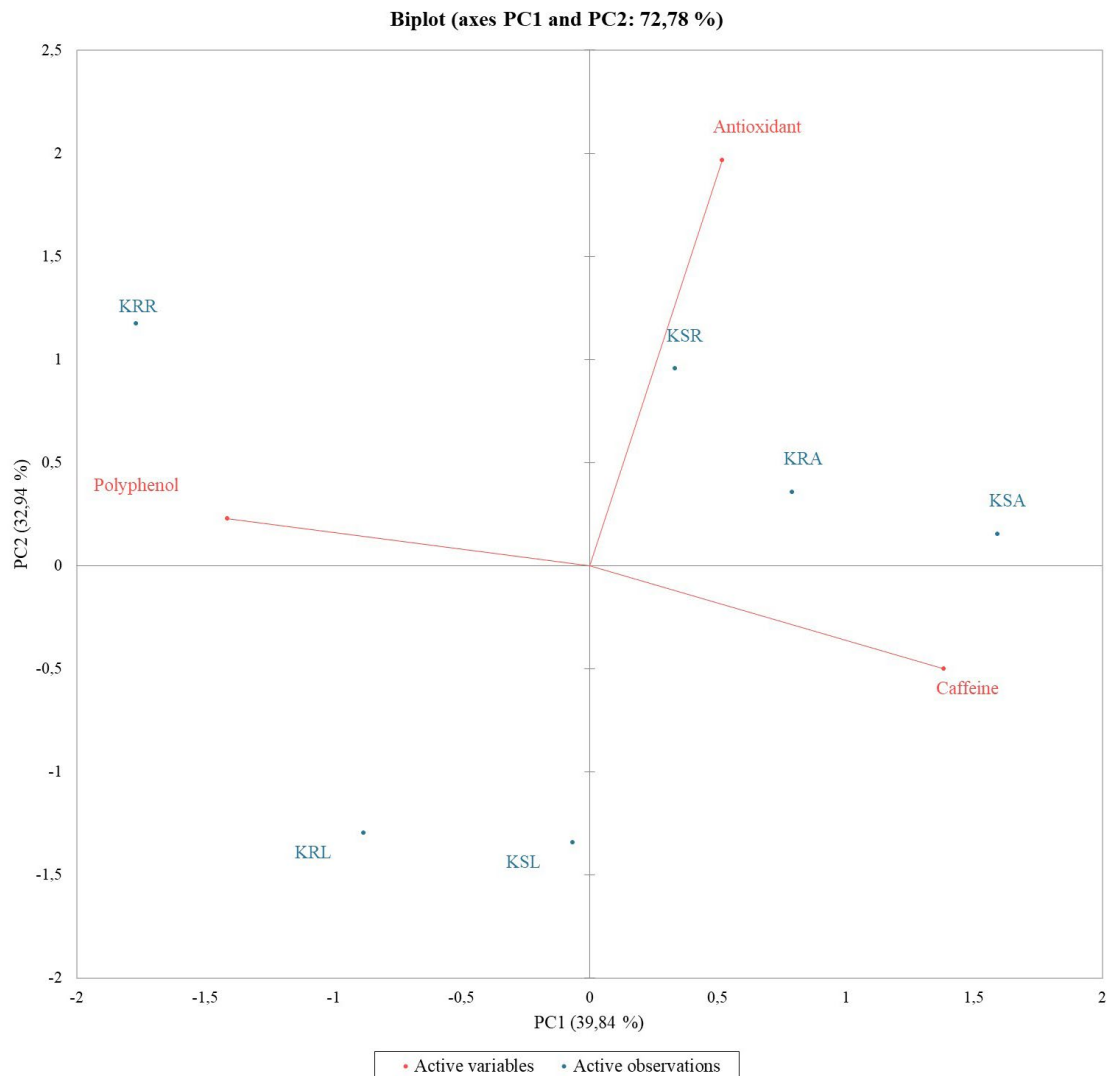


Figure 1: Diversity pattern among three species of coffee bean skin and various harvesting methods based on the phytochemical. The blue point indicates the position of the CBS species with different harvesting technique; The red point indicates the position of the tested phytochemical traits. Polyphenol = total phenolic content; Caffeine = caffeine contents; Antioxidant = antioxidant activity (DPPH); KRR = strip-picked Robusta; KSR = selectively-picked Robusta; KRA = strip-picked Arabica; KSA = selectively-picked Arabica; KRL = strip-picked Liberica; KSL = selectively-picked Liberica.

phenomena occurred due to the formation of some chemical compound during the ripening stage of the coffee plant. Coffee at its ideal maturity level would provide better chemical components than fruit gathered at green and yellow maturity levels (Maxiselly et al., 2023b).

A statistical technique called principal component analysis (PCA) is used to explain sample differences and to learn more about the factors that primarily affect sample similarities and differences. Using a corresponding set of scores and loading plots, this process extracts the recurring patterns from the data matrix. With PCA, we can reduce the number of dimensions, explore data to find relationships between objects, estimate the correlation structure of the variables, and determine how many components (a linear combination of original features) are needed to explain the majority of the variance with the least amount of information lost (Rodriguez-Delgado et al., 2002; Šamec et al., 2016).

The correlation between the qualities based on the vector positions was found using the PCA graph. Estimating the correlation between the qualities was made easier by the angle that formed between the vectors. According to Kohler and Luniak (2005), trait vectors forming an acute angle (closer to 0) show a high positive correlation between the traits, whereas trait vectors forming an obtuse angle (near to 180) show a strong negative correlation. The location of the coffee sample points and the trait vectors show how big the traits are in the tested sample. A species is said to have a high value for a characteristic when it is near to that trait (Jolliffe, 2002). Figure 1 showed that strip-picked *C. canephora* was close to the TPC trait, indicating the strip-picked Robusta coffee beans was superior in this properties than other species and harvesting technique. Similarly, selectively picked Robusta coffee beans possessed strong correlation with the antioxidant activity trait. In terms of caffeine content, the figure showed a close correlation between Arabica CBS with both harvesting technique with the caffeine trait. Robusta coffee beans are known to have a greater caffeine concentration than Arabica and Liberica beans (Davis et al., 2022). However, different plant species and even different portions of the same species have varied concentrations of secondary metabolites, including caffeine (Achakzai et al., 2009). This might indicate the difference in the caffeine content exhibited by the CBS and other parts of the coffee plant. In contrast with Arabica and Robusta, the figure showed that Liberica exhibited low correlation with all traits.

5 CONCLUSIONS

This study revealed that species and harvesting methods influenced the phytochemical properties of the CBS. Moreover, the correlation of the investigated phytochemical parameters exhibited by the skin of three

coffee bean species (Arabica, Robusta, and Liberica) harvested by 2 different techniques were visualized using principal component analysis. The results pointed out that different species with different harvesting technique affect the phytochemical content exhibited by the bean skin. The *C. canephora* showed high correlation with the TPC and the *C. arabica* bean skin showed high correlation with the caffeine content. The findings from this study suggests the possibility of utilizing the waste from coffee industry, especially the skin, to be used further in the development of product with considerable amount of bioactive compounds. Nevertheless, coffee beans harvested from different region might provide different outcome.

6 AUTHORS' CONTRIBUTION

Conceptual idea: Maxiselly, Y.; Bakti, C.; Methodology design: Maxiselly, Y.; Renaldi, G.; Data collection: Maxiselly, Y.; Sari, D.N.; Data analysis and interpretation: Renaldi, G.; Maulana, H.; Nusifera, S.; Writing and editing: Maxiselly, Y.; Bakti, C.; Renaldi, G.; Sari, D.N.; Nusifera, S.; Maulana, H.

7 REFERENCES

- ABDELWARETH, A.; ZAYED, A.; FARAG, M. A. Chemometrics-based aroma profiling for revealing origin, roasting indices, and brewing method in coffee seeds and its commercial blends in the Middle East. **Food Chemistry**, 349:129162, 2021.
- ACHAKZAI, A. K. K. et al. Response of plant parts and age on the distribution of secondary metabolites on plants found in Quetta. **Pakistan Journal of Botany**, 41(5):2129-2135, 2009.
- ALAM, I.; WARKOYO, W.; SISKAWARDANI, D. Karakteristik tingkat kematangan buah kopi robusta (*Coffea canephora* A. Froehner) dan buah kopi arabika (*Coffea arabica* Linnaeus) terhadap mutu dan cita rasa seduhan kopi. **Food Technology and Halal Science Journal**, 5:169-185, 2023.
- AL-YOUSEF, H. M.; AMINA, M. Essential oil of *Coffea arabica* L. Husks: A brilliant source of antimicrobial and antioxidant agents. **Biomedical Research**, 29(1):174-180, 2018.
- APAK, R. Current issues in antioxidant measurement. **Journal of Agricultural and Food Chemistry**, 67:9187-9202, 2019.
- BHAWANI, S. A.; FONG, S. S.; IBRAHIM, M. N. M. Spectrophotometric analysis of caffeine. **International Journal of Analytical Chemistry**, 2015(1):170239, 2015.

- BRITTA F. **The craft and science of coffee**. Amsterdam: Elsevier Inc., p. 1-16, 2017.
- CARMEN, M. T. et al. Coffee pulp: An industrial by-product with uses in agriculture, nutrition and biotechnology. **Reviews in Agricultural Science**, 8:323-342, 2020.
- CHIVA-BLANCH, G.; VISIOLI, F. Polyphenols and health: Moving beyond antioxidants. **Journal of Berry Research**, 2:63-71, 2012.
- DA SILVA, C. J. R. S. et al. Determining caffeine content in different coffee types. **Demetra: Food, Nutrition and Health**, 13:477-484, 2018.
- DA SILVA, M. R. et al. Metabolite characterization of fifteen by-products of the coffee production chain: From farm to factory. **Food Chemistry**, 369:130753, 2022.
- DAVIS, A. P. et al. The re-emergence of Liberica coffee as a major crop plant. **Nature Plants**, 8:1322-1328, 2022.
- ECHEVERRIA, M. C.; NUTI, M. Valorisation of the residues of coffee agro-industry: Perspectives and limitations. **The Open Waste Management Journal**, 10:13-22, 2017.
- GIAMPIERI, F. et al. Strawberry as a health promoter: An evidence based review. **Food and Function**, 6:1386-1398, 2015.
- GOUVEA, B. M. et al. Feasibility of ethanol production from coffee husks. **Biotechnology Letters**, 31:1315-1319, 2009.
- JOLLIFFE, I. T. **Principal component analysis**: Springer series in statistics. New York, NY, USA, Springer, 2002. 405p.
- KOHLER, U.; LUNIAK, M. Data inspection using biplots. **Stata Journal**, 5:208-223, 2005.
- MATHUR, R. et al. Bioprocess of robusta cherry coffee with polyphenol oxidase and quality enhancement. **European Food Research and Technology**, 240:319-325, 2014.
- MAULANA, H. et al. Heritability and selection using GGE biplots and the sustainability index (SI) of maize mutants under different cropping systems in upland. **Sustainability**, 15:6824, 2023.
- MAXISELLY, Y. et al. Relationship analysis based on phytochemical contents among coffee pulp from three coffee species collected in Southern Thailand and Jambi, Indonesia. **Biodiversitas**, 24(10): 5439-5445, 2023a.
- MAXISELLY, Y. et al. Morpho-physiological traits and phytochemical compositions of coffea canephora beans from Lampung for various harvesting stages and soaking durations. **International Journal of Plant Biology**, 14:746-754, 2023b.
- MUSSATTO, S. I. et al. Production, composition, and application of coffee and its industrial residues. **Food Bioprocess Technol** 4:661-672, 2011.
- NGAMSUK, S.; HUANG, T-C.; HSU, J-L. Determination of phenolic compounds, procyanidins, and antioxidant activity in processed *Coffea arabica* L. leaves. **Foods**, 8:389, 2019.
- ORREGO, D.; ZAPATA-ZAPATA, A. D.; KIM, D. Optimization and scale-up of coffee mucilage fermentation for ethanol production. **Energies**, 11:1-12, 2018.
- PATAY, É. B. et al. Antioxidant potential, tannin and polyphenol contents of seed and pericarp of three *coffea* species. **Asian Pacific Journal of Tropical Medicine**, 9:366-371, 2016.
- QUINTERO-JARAMILLO, J. A. et al. A review of caffeine adsorption studies onto various types of adsorbents. **The Scientific World Journal**, 9998924, 18 pages, 2021.
- RENALDI, G. et al. Physicochemical, textural, and sensory qualities of pectin/gelatin gummy jelly incorporated with garcinia atroviridis and its consumer acceptability. **International Journal of Gastronomy and Food Science**, 28:100505, 2022.
- RODRIGUEZ-DELGADO, M-A. et al. Principal component analysis of the polyphenol content in young red wines. **Food Chemistry**, 78:523-532, 2002.
- SALAR, R. K.; PUREWAL, S. S.; SANDHU, K. S. Relationships between DNA damage protection activity, total phenolic content, condensed tannin content and antioxidant potential among indian barley cultivars. **Biocatalysis and Agricultural Biotechnology**, 11:201-206, 2017.
- ŠAMEC, D. et al. Assessment of the differences in the physical, chemical and phytochemical properties of four strawberry cultivars using principal component analysis. **Food Chemistry**, 194:828-834, 2016.
- SAUD, S.; SALAMATULLAH, A. M. Relationship between the chemical composition and the biological functions of coffee. **Molecules**, 26:7643, 2021.
- SOCALA, K. et al. Neuroprotective effects of coffee bioactive compounds: A review. **International Journal of Molecular Sciences**, 22:107, 2021.

TAKASHIMA, M. et al. Assessment of antioxidant capacity for scavenging free radicals in vitro: A rational basis and practical application. **Free Radical Biology and Medicine**, 52:1242-1252, 2012.

VELÁSQUEZ, S.; BANCHÓN, C. Influence of pre-and post-harvest factors on the organoleptic and physicochemical quality of coffee: A short review.

Journal of Food Science and Technology, 60(10):2526-2538, 2023.

VIONITA, S.; KARDHINATA, E. H.; DAMANIK, R. I. Morphology identification and description of coffee plants (*Coffea* sp.) in Karo district. **IOP Conference Series: Earth and Environmental Science**, 782:042051, 2021.