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Discriminating Geographical Origin of Cashew Nuts Based on the Combination of Multi-elements and Chemical Component Analysis

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Abstract*— This study aims to distinguish Indonesian cashew nuts' geographical origin based on their elemental profiles and chemical composition. Nine elements and five chemical components of cashew nut samples were analyzed. The profiles of four micro-elements, Zn, Cu, Mn, Cr, and five macro elements, K, Ca, Mg, Fe, Na, of Indonesian cashew nuts were determined using Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES). Simultaneously, the chemical components of moisture, ash, total protein, total fat, and carbohydrate contents were measured using the AOAC standard. The combination of elemental profiles was then analyzed with a scatterplot matrix diagram and a multivariate statistical technique, Canonical Discriminant Analysis (CDA). Inter-region discrimination among four major Indonesian cashew nuts producers was achieved by applying CDA. Sodium (Na), calcium (Ca), potassium (K), manganese (Mn), zinc (Zn), and total protein were the best descriptors for cashew nuts origin. According to the findings, the most abundant element in cashew nuts is potassium (K), followed by magnesium (Mg), and calcium (Ca) (Ca). Fat is the most abundant chemical composition in cashew nuts at the same time. Potassium (K), magnesium (Mg), and calcium (Ca) concentrations showed major regional variations. On the other hand, zinc (Zn) and manganese (Mn) are two micro-elements that may help identify the origin of cashew nut samples. The use of a Canonical Discriminant Analysis scatters plot to visualize the origin of Indonesian cashew nut samples was less successful based on micro-element concentrations. The CDA scatter plot application based on macroelements, and the CDA scatter plot application based on a mixture of micro- and macro-elements produced better results than the CDA scatter plot application based on micro-elements. Furthermore, the best visual separation was achieved using a CDA scatter plot based on a combination of elemental profiles and protein concentration. For a complete characterization of cashew nuts, further research with a large number of samples is needed.

***Keywords*— Canonical Discriminant Analysis; cashew nuts; geographical origin; ICP-OES; Indonesia.**

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I. INTRODUCTION

Cashew nuts are a favorite type of snack. Apart from their distinctive taste, the nuts are highly nutritious. In general, every 100 grams of the nuts contain 21% protein, 46% fat, 25% carbohydrates with low saturated fat content, and rich vitamins B1, B2, and B3 [1]. Global cashew nut production also continues to increase. In 2000 global cashew nut production was 2.08 million tons. However, in 2018 cashew nut production nearly tripled to 5.93 million tons [2] with significant cashew nut producers from South East Asia and Africa. Indonesia is one of the leading cashew nut producers in South East Asia. In 2018, Indonesia produced 136,402 tons of cashew nuts [2] and exported 62,811 tons of cashew nuts, equivalent to US$ 175.7 million [3]. The cashew plantations continue to increase in the country, and 2017 reached 506,752 hectares, spread across the archipelago from Java, Sulawesi, and Bali [3].

The quality of food products, including cashew nuts, is often closely related to the area of origin, either due to human factors, natural factors [4], [5], or a combination of these two factors. Such kind of product is called Geographical Indication (GI) products [6]. Two cashew nut products in Indonesia have been registered as GI products, namely Kubu cashew nut from Karangasem, Bali Province, and Muna cashew nut from Muna, Southeast Sulawesi Province.

The registration of GI products indicates producers' desires to protect their products from adulteration [7]. Indonesia can increase cashew nut's GI products because of the widespread cashew cultivation across the archipelago. Therefore, research on the discrimination of GI's food products, especially cashew nut products, is essentials.

The analytical method of quality parameters combined with chemometrics is one of the most effective methods for determining products' origin [8]. The geographical environment is an essential factor that can influence the chemical composition of food products. The relationship between chemical components, like proximate content, and cultivation areas, was reported in some studies [9], [10]. However, the proximate use is considered unfavorable because of its volatile nature due to the storage process and transportation. Besides, minerals are the parameters commonly used to identify the origin of a product. A food product's mineral composition reflects the mineral composition in the environment and the soil where the plant is cultivated [11]. Furthermore, mineral content in agricultural materials tends to be stable during the transportation and storage process.

The use of mineral content to recognize the origin of food products has been successfully applied both for fresh food ingredients such as snake fruit [12]; rice [13]–[17]; potatoes [18]–[20]; coffee beans [21]–[25], and processed products such as coconut sap [10]; wine [26]; and lemon juice [27]. The analysis of mineral content was also conducted for cashew nut products [28]–[32]. Unfortunately, most of the previous studies on cashew nuts were only focused on mineral composition analysis and not determining the origin of the products. Therefore, this research aims to establish the potential of integrating elemental profiles and chemical component analysis to discriminate cashew nuts' geographical origins in Indonesia.

II. Material and Method

A. Samples

Cashew nut samples were collected from four regions in Indonesia, namely Karangasem (Bali Province), Muna (Southeast Sulawesi Province), Wonogiri (Central Java Province), and Gunungkidul (Yogyakarta Special Region). Karangasem and Muna are the origins for Kubu cashew nut and Muna cashew nut, respectively, two cashew nut's GI products in Indonesia [33], [34]. At the same time, Wonogiri and Gunungkidul are areas of origin for cashew nut, potentially registered as GI products [35]. From each cultivation region, one to four sub-regions were selected based on the level of production.

TABLE I
SAMPLES GEOGRAPHICAL ORIGIN INFORMATION

Samples	Region	Sub-region	Latitude Coordinates	Longitude Coordinates
1,2,3	Wonogiri	Jatiroto	7°52'25" - 7°53'39"	111°04'36" - 111°06'09"
4,5,6		Ngadirojo	7°49'24" - 7°50'44"	110°59'06" - 111°00'54"
7,8,9		Sidoharjo	7°50'45" - 7°53'11"	111°03'12" - 111°03'57"
10,11,12		Jatisrono	7°49'31" - 7°50'49"	111°08'32" - 111°10'34"
13,14,15	Gunungkidul	Semin	7°50'11" - 7°52'12"	110°42'43" - 110°45'04"
16,17,18		Ngawen	7°47'58" - 7°52'27"	110°40'10" - 110°43'39"
19,20,21	Muna	Tongkuno	5°07'51" - 5°09'42"	122°29'41" - 122°33'14"
22,23,24		Tongkuno Selatan	5°09'57" - 5°11'39"	122°30'21" - 122°31'16"
25,26,27	Karangasem	Kubu	8°13'55" - 8°17'30"	115°32'15" - 115°35'24"

Samples were obtained at physiological maturity and collected directly from the site. A total of three cultivation areas were selected from each sub-region. In each cultivation area of one hectare, cashew samples were taken from ten cashew trees to obtain 1.5 kg to 2 kg of nuts samples. A total of 20 g nuts were taken and analyzed less than one week after harvested. Table 1 provides samples of geographical origin information.

B. Samples Preparation

Cashew nut samples were shelled using a manual cashew nut peeler. After shelling, the nuts were withdrawn and roasted in an oven (Getra RFL-12SS, GEA, Indonesia) at 80°C for 2 hours. The cashew husks were then shelled by squeezing and winnowing to achieve cream color kernels. The kernels were floured using a mortar and sieved using a sieve with a mesh size of 0.5 mm. A total of 1 gram of floured sample was then dissolved with 5 ml of HNO_3 and 5 ml of HCl. The sample solution was then used as the basis for analysis. The concentration of nine elements, namely Fe, Ca, Na, Mg, K, Zn, Mn, Cr, and Cu was then measured using Inductively Coupled Plasma-Optical Emission Spectrometry (Varian 715-ES, Agilent, Australia) according to EPA Method 6010D standard [36].

Chemical composition analysis includes the determination of moisture and ash contents using the thermogravimetric method, total protein content with micro-Kjeldahl, total fat content using Soxhlet extraction method, and carbohydrates by difference were conducted according to AOAC standards [37].

C. Statistical Analysis

Elemental profiles and chemical composition are expressed as mean ± standard deviation. Differences among elemental profiles and chemical composition in the cashew nut samples were examined using one-way ANOVA followed by a post hoc Tukey HSD test. Statistical significance was specified as $p \leq 0.05$. A multivariate data analysis technique, namely Canonical Discriminant Analysis (CDA) [38]-[39], was carried out on the concentrations of elements to bring the samples' discrimination. All the statistical analysis was evaluated using SPSS (v.25, IBM, Chicago, IL).

III. Result and Discussion

A. Analysis of Macro and Micro Elements

The mean results for Fe, Ca, Na, K, Mg, Mn, Zn, Cu, and Cr concentrations of cashew nut samples from various regions are presented in Table 2. The data obtained were then used to discriminate cashew nut samples from various regions. The order of the macro elements concentration of the samples was as follows: K > Mg > Ca > Na > Fe (Table 2). This trend was similar to previous studies [28], [30], [32]. Based on the macro elements concentrations, potassium (K) was the highest concentration, with an overall mean of 6995.40 mg/kg, higher than cashew nut samples from Nigeria [32], Vietnam, India, Brazil, and Ivory Coast [30]. Potassium (K) is needed to balance human fluid, maintain blood pressure, and balance nerve transmission [40]. Thus, cashew nut primarily originated from Indonesia, is a good source of potassium (K).

The overall mean of magnesium (Mg) concentration in the current study (2651.13 mg/kg) relatively similar to the previous research conducted by Naozuka *et al.* [41] of 2794 mg/kg. The importance of magnesium (Mg) is not only for protein formation but also for minimizing muscle contraction. An adequate amount of magnesium (Mg) can help the human body to maintain the immune system and nerve transmission. Magnesium (Mg) also assists in avoiding constipation [40].

The overall mean of calcium (Ca) in the current study (262.70 mg/kg) was lower than the overall mean of the study conducted by Nnorom and Ewuzie [32] but had similarities with the study conducted by Naozuka *et al.* [41]. Calcium (Ca) is an essential element for healthy teeth and bones, nerve functioning, and blood pressure regulation. It also helps to relax muscles and maintain the immune system [40].

TABLE III

MEAN CONCENTRATIONS (MG/KG) OF ELEMENTS IN THE CASHEW NUT SAMPLES

Regions	Fe	Ca	Na	K	Mg	Mn	Zn	Cu	Cr
Wonogiri									
Jatiroto	71.79 ± 11.2^{ab}	300.86 ± 8.8^{de}	51.82 ± 6.3^{a}	7088.92 ± 347.1^{ab}	2588.35 ± 90.0^{a}	11.50 ± 0.4^{ab}	48.83 ± 3.3^{b}	17.20 ± 0.1^{abc}	2.05 ± 0.7^{ab}
Ngadirojo	76.94 ± 24.1^{ab}	281.08 ± 19.5^{cd}	40.35 ± 6.9^{a}	7278.22 ± 433.9^{ab}	2790.50 ± 165.6^{a}	12.93 ± 0.8^{abc}	46.41 ± 3.1^{b}	19.25 ± 1.8^{bc}	5.13 ± 3.2^{b}
Sidoharjo	48.48 ± 11.7^{a}	334.37 ± 9.7^{e}	48.17 ± 4.2^{a}	8232.82 ± 291.0^{b}	2916.48 ± 23.7^{a}	14.21 ± 1.0^{bcd}	63.33 ± 6.0^{bc}	18.82 ± 1.3^{bc}	1.79 ± 1.1^{ab}
Jatisrono	46.12 ± 11.7^{a}	221.19 ± 16.4^{b}	35.18 ± 5.2^{a}	7054.68 ± 225.5^{ab}	2722.09 ± 185.6^{a}	10.47 ± 0.6^{a}	48.80 ± 1.4^{b}	17.74 ± 2.3^{abc}	2.98 ± 1.9^{ab}
Pooled	60.83 ± 19.6	284.40 ± 44.7^{B}	43.88 ± 8.4^{A}	7413.66 ± 576.8^{B}	2754.36 ± 167.8	12.28 ± 1.6^{A}	51.90 ± 7.7^{A}	18.25 ± 1.6	2.99 ± 2.2
Gunungkidul									
Semin	61.11 ± 17.2^{ab}	246.59 ± 25.0^{bc}	56.83 ± 7.2^{a}	7100.04 ± 105.3^{ab}	2697.23 ± 89.9^{a}	9.720 ± 0.7^{a}	46.82 ± 4.5^{b}	19.82 ± 0.6^{c}	3.67 ± 2.1^{ab}
Ngawen	51.46 ± 8.2^{ab}	290.63 ± 13.0^{bc}	89.83 ± 9.9^{a}	7210.57 ± 246.6^{ab}	2386.63 ± 72.6^{a}	11.73 ± 0.8^{ab}	56.70 ± 4^{b}	14.00 ± 1.0^{a}	2.20 ± 0.4^{ab}
Pooled	56.29 ± 13.1	268.61 ± 30.0^{B}	73.33 ± 19.7^{A}	7155.30 ± 180.0^{B}	2541.93 ± 185.2	10.73 ±1.3^{A}	51.80 ± 6.6^{A}	16.91 ± 3.3	2.94 ± 1.6
Muna									
Tongkuno	85.62 ± 4.4^{ab}	284.53 ± 24.7^{bc}	177.0 ± 19.4^{c}	6347.93 ± 1408.8^{ab}	2648.92 ± 733.3^{a}	17.27 ± 2.2^{d}	81.57 ± 18.2^{c}	21.31 ± 1.1^{c}	0.15 ± 0.2^{a}
Tongkuno Selatan	68.44 ± 5.3^{ab}	329.43 ± 20.6^{cd}	83.70 ± 6.2^{b}	5797.50 ± 339.1^{a}	2231.52 ± 106.6^{a}	12.88 ± 0.8^{abc}	22.92 ± 1.4^{a}	15.18 ± 1.5^{ab}	1.31 ± 0.1^{ab}
Pooled	63.39 ± 10.9	307.00 ± 31.9^{B}	130.7 ± 52.7^{B}	6072.70 ± 964.8^{A}	2440.22 ± 521.4	15.07 ± 2.8^{B}	52.25 ± 34.1^{A}	18.24 ± 3.6	0.73 ± 0.7
Karangasem									
Kubu	69.39 ± 10.9^{ab}	75.660 ± 21.9^{aA}	46.72 ± 17.6^{aA}	6847.97 ± 1372.2^{abA}	2878.44 ± 338.0^{a}	15.38 ± 2.8^{cdB}	195.9 ± 12.4^{dB}	17.91 ± 2.4^{abc}	2.70 ± 1.4^{ab}
Average	63.71 ± 16.8	262.70 ± 77.2	69.95 ± 43.4	6995.40 ± 869.8	2651.13 ± 338.0	12.90 ± 2.6	67.93 ± 12.4	17.91 ± 2.5	2.44 ± 1.9

Different superscript letters within the columns indicate significant disparities ($p < 0.05$) in the mean concentrations of elements. Lowercase letters indicate significant disparities within regions, while capital letters indicate significant disparities of inter-regions.

TABLE IIIII

MEAN CONCENTRATIONS (%) OF CHEMICAL COMPOSITIONS IN THE CASHEW NUT SAMPLES

Regions	Moisture	Ash	Protein	Fat	Carbohydrate
Wonogiri					
Jatiroto	4.06 ± 0.02^{b}	2.50 ± 0.04^{bcd}	15.59 ± 0.11^{b}	43.90 ± 0.29^{b}	33.95 ± 0.24^{cd}
Ngadirojo	4.05 ± 0.00^{b}	2.28 ± 0.05^{a}	16.01 ± 0.41^{bc}	40.15 ± 0.72^{a}	37.50 ± 1.08^{e}
Sidoharjo	4.03 ± 0.04^{b}	2.57 ± 0.01^{d}	15.89 ± 0.06^{bc}	43.19 ± 0.15^{b}	34.35 ± 0.11^{d}
Jatisrono	3.99 ± 0.03^{ab}	2.54 ± 0.05^{cd}	15.82 ± 0.18^{bc}	44.50 ± 0.66^{b}	33.15 ± 0.45^{cd}
Pooled	4.03 ± 0.04	2.47 ± 0.12	15.83 ± 0.26^{B}	42.93 ± 1.80^{A}	34.74 ± 1.80^{B}
Gunungkidul					
Semin	4.07 ± 0.02^{b}	2.47 ± 0.03^{bc}	16.44 ± 0.24^{cd}	40.34 ± 0.65^{a}	36.69 ± 0.37^{e}
Ngawen	4.09 ± 0.00^{b}	2.57 ± 0.02^{d}	16.81 ± 0.36^{d}	43.95 ± 0.54^{b}	32.59 ± 0.92^{c}
Pooled	4.07 ± 0.02	2.51 ± 0.05	16.62 ± 0.34^{C}	42.14 ± 2.05^{A}	34.64 ± 2.33^{B}
Muna					
Tongkuno	3.92 ± 0.09^{a}	2.53 ± 0.04^{bcd}	15.38 ± 0.41^{ab}	47.07 ± 0.57^{c}	30.99 ± 0.03^{b}
Tongkuno Selatan	4.07 ± 0.02^{b}	2.57 ± 0.01^{d}	15.75 ± 0.07^{b}	49.09 ± 0.39^{d}	28.52 ± 0.49^{a}
Pooled	3.99 ± 0.10	2.55 ± 0.03	15.61 ± 0.30^{B}	48.08 ± 1.19^{B}	29.76 ± 1.39^{A}
Karangasem					
Kubu	3.99 ± 0.00^{ab}	2.45 ± 0.00^{b}	14.91 ± 0.02^{aA}	49.95 ± 0.28^{dB}	28.70 ± 0.03^{aA}
Total Average	4.03 ± 0.06	2.49 ± 0.09	15.86 ± 0.57	44.68 ± 3.35	33.95 ± 3.06

Different superscript letters within the columns indicate significant disparities ($p < 0.05$) in the mean concentrations of chemical composition. Lowercase letters indicate significant disparities within regions, while capital letters indicate significant disparities of inter-regions.

Sodium (Na) is needed to maintain muscle contraction and nerve transmission, balance electrolytes and fluid, and maintain heart function [40]. This study's overall mean of sodium (Na) concentration (69.95 mg/kg) had close similarity with cashew nut samples from Ivory Coast [30]. However, this result was lower than the concentration of sodium (Na) found in cashew nut samples from Nigeria [32], Vietnam, India, and Brazil [30].

Iron (Fe) brings oxygen from the lungs to the entire body cells. It has importance for energy metabolism, forming hemoglobin in red blood cells, and a medium for electron transportation within cells. The overall mean of iron (Fe) in the present study (63.71 mg/kg) had a similarity with the concentration of iron (Fe) found in cashew nut samples originated from Vietnam and Nigeria [30], [32].

Cashew nuts are a good source of micro-elements such as copper (Cu), zinc (Zn), and manganese (Mn) which are important for metabolic processes in the human body. Based on the mean concentration of micro-elements in analyzed samples, the order of the micro-elements of the samples was as follows: Zn > Cu > Mn > Cr (Table 2). This study's result did not differ significantly with cashew nut samples originated from Nigeria [32]. However, there were significant differences in Cr concentrations, whereas the results obtained in this study are higher than cashew nut samples originated from Nigeria.

The overall mean of zinc (Zn) content in this study (67.93 mg/kg) was higher than cashew nut samples originated from Vietnam, India, Brazil, and Ivory Coast [30], [41]. However, the current study's result had close similarities with the Nigerian cashew nut samples [30]. Zinc (Zn) is essential for the humans metabolic. It produces protein and genetic material, structures enzymes, and enhances smell. Zinc (Zn) is also needed for sperm production and sexual maturation [40].

The overall mean of copper (Cu) in the present study (17.91 mg/kg) was lower compared to Nigerian cashew nuts [32]. Still, this finding was higher than cashew nut samples originated from Brazil [41]. Copper (Cu) plays a vital role in fighting infections; repairs injured tissues and neutralizes free radicals leading to severe cell damage. Furthermore, copper (Cu) was a structural part of plentiful enzymes and required for Fe and protein metabolism [40].

Manganese (Mn) is essential for the natural growth of the human bone structure. It is part of enzymes and beneficial for post-menopausal women and avoiding osteoporosis. Manganese (Mn) is also vital for the nervous system's proper activity and the brain's normal functioning [40]. The overall mean of manganese (Mn) concentration in the current study (12.90 mg/kg) was lower than that of cashew nut samples from Nigeria [32]. However, it had close similarity with the Brazilian cashew nut samples [41].

The result of chromium (Cr) concentrations in the present study (2.44 mg/kg) was higher compared to cashew nut samples from Nigeria [32]. Reports indicate that chromium (Cr) is essential in the metabolism of carbohydrates and fats. Chromium (Cr) collaborate with insulin to maintain glucose levels [40]. However, at sufficiently high concentrations, chromium (Cr) is toxic and carcinogenic. Total chromium (Cr) in drinking water is generally less than two µg/litre [42].

B. *Estimation of Elements Intake*

Previous study revealed that the consumer consumes 35-79 grams of cashew nuts per day [32]. Thus, the daily intake of Fe, Ca, Na, K, Mg, Mn, Zn, Cu, and Cr derived from cashew nuts in this study was measured based on this range. The elements intake was compared with Reference Daily Intake (RDI) suggested by FAO [44], Institute of Medicine (IOM) [45], and the Indonesian Health Ministry [46].

A daily intake of 35-79 grams of cashew nuts will provide the human body with 2.2-5.1 mg of iron (Fe), 9.2-20.8 mg of calcium (Ca), 92.8-209.4 of magnesium (Mg), and 2.4-5.4 mg of zinc (Zn). The Recommended Nutrient Intakes (RNI) of Fe is 9.1 mg/day [44]. Thus, cashew nuts' daily consumption will be sufficient for 24-56% of Fe's total requirement. However, daily consumption of cashew nuts can only supply less than 3% of the daily calcium (Ca) requirement for adults since the recommended daily intake for Ca is 1.000 mg/day [44]. RNI of magnesium (Mg) for adults is 220 mg/day, while 350 mg are suggested as tolerable limits for magnesium's daily intake [44]. Daily consumption of cashew nuts will provide 42-95% of the human body's need for magnesium (Mg). The average RNI of Zn for adults is 6 mg/day, while the upper level of zinc (Zn) intake for an adult is set at 45 mg/day. Based on this study, cashew nuts were a good source of zinc (Zn). Consuming 79 grams of cashew nuts a day will be sufficient for 90% of the daily zinc (Zn) requirement.

Daily reference values of 1.500 mg for sodium (Na) and 4.700 mg for potassium (K) were set by the Indonesian Health Ministry [46]. Na's intake on the consumption of 35-79 g cashew nuts was only between 2.4 and 5.5 mg per day. However, consuming cashew nuts 35-79 g per day will provide 5.2-11.7% of potassium (K) needs.

Daily consumption of 35-79 g cashew nuts will provide 0.6-1.4 mg of copper (Cu) and 0.08-0.19 mg of chromium (Cr). These figures were lower than tolerable upper intake levels of Cu (10 mg/day) set by The Institute of Medicine [45]. Although a tolerable upper intake level of Cr has not been derived, WHO considered that the chromium (Cr) supplement should not exceed 0.25 mg/day [45]. Therefore, daily consumption of 35-79 grams of nuts is unlikely to pose any health risk.

C. *Chemical Composition in Cashew Nut Samples*

The chemical concentration of cashew nut samples is represented in Table 3. The overall mean of moisture content in the cashew nut samples was 4.03%. According to Rico, Bullo, and Salas-Salvado [30], the moisture content of cashew nut was 3.5 to 4.4%. Thus, the present study's results were within the reported range. The ash content of cashew nut samples (2.50%) was similar to the cashew nut values originated from India [30]. This study's total protein content was 15.86%, which was lower than the concentration of cashew nut samples originated from Nigeria [28]. The overall mean of total fat content in this study (44.68%) was identical to the conctration informed by Griffin and Dean [31]. The carbohydrate of cashew nut samples was 32.93%, which was similar to the results provided by Emelike, Barber, and Ebere [29].

Fat, protein, and carbohydrate are significantly dissimilar ($p < 0.05$) among the other regions' samples. The fat concentration was the most abundant in the Karangasem samples and the fewest in the Gunungkidul samples. The protein concentration in Gunungkidul samples was 16.63%, higher than Wonogiri, Muna, and Karangasem samples. The carbohydrate concentration was higher in samples from Wonogiri and Gunungkidul than in Muna and Karangasem.

D. Scatterplot Matrix

The scatterplot matrix diagram was deployed to discriminate Indonesian cashew nut origin based on their elemental profiles. Figure 1 shows the scatterplot matrix diagram combined of two macro elements, while Figure 2 shows the scatterplot matrix diagram combined of two micro-elements.

Discrimination of the cashew nuts samples from certain areas, such as Karangasem, can be done using a simple two-elements combination scatter plot. However, the samples' macro elements scatterplot shows an overlap for all elements measured between the four groups, except the samples originated from Karangasem. The same condition also takes place in the micro-elements scatterplot, which results in the discrimination of the samples was challenging. Hence, the multivariate analysis involving nine elements was deployed. The use of multiple elements analysis combined with multivariate statistical analysis such as Canonical Discriminant Analysis (CDA) to distinguish geographical origins has been carried out in various studies, including geographical origin discrimination of foxtail [9], coconut sap sample [12], and espresso coffee [43].

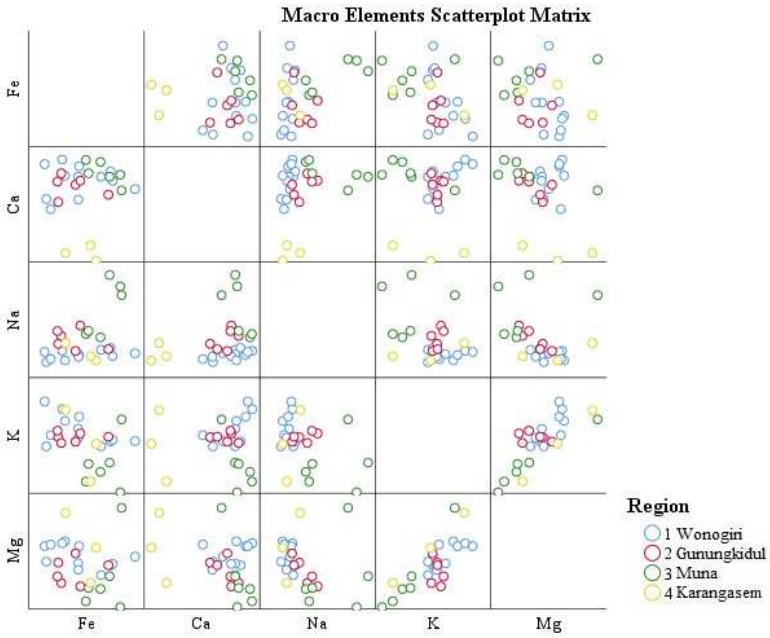

Fig. 1 Scatterplot matrix diagram of macro elements on cashew nut samples

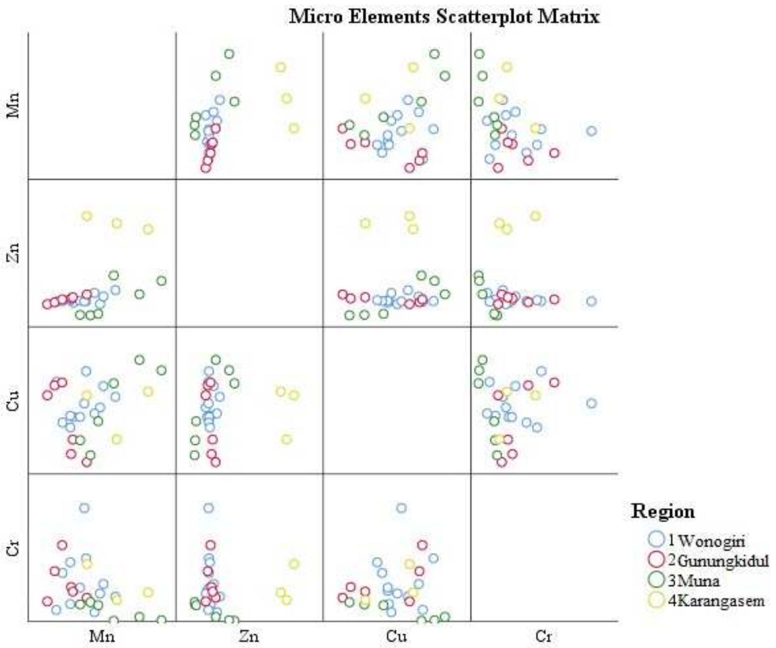

Fig. 2 Scatterplot matrix diagram of micro elements on cashew nut samples

E. Discrimination of Geographical Origin

Canonical Discriminant Analysis (CDA) was carried out to distinguish the Indonesian cashew nuts' origin based on their elemental profiles. The first attempt was to distinguish the geographical origin of the samples using micro-element concentrations. The CDA axes in two dimensions achieved by the analysis for micro-elements of copper (Cu), zinc (Zn), chromium (Cr), and manganese (Mn) are shown in Figure 3.

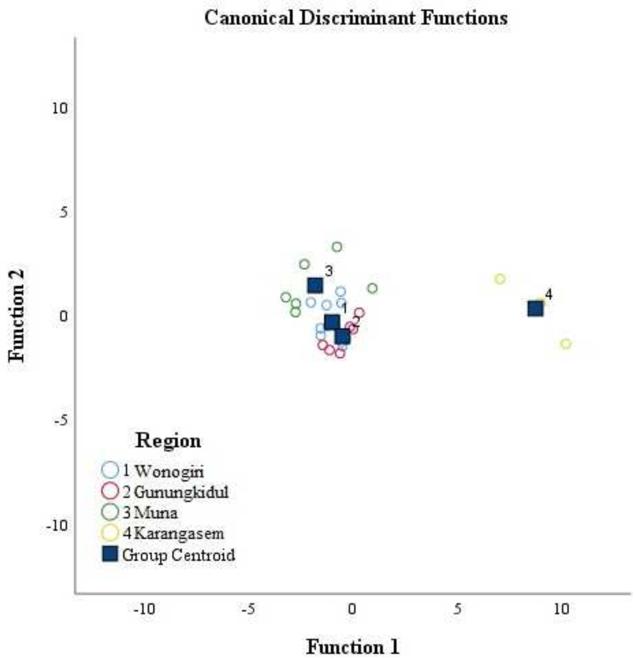

Fig. 3 Canonical Discriminant Analysis scatter plot based on Zn, Cu, Mn, and Cr for cashew nuts samples

The *Test of Equality of Group Means* was deployed to determine the significance of micro-elements to discriminate. Among four micro-elements, zinc (Zn) and manganese (Mn) were two micro-elements that can be differentiated significantly (*p-value* < 0.05). The first two canonical functions obtained from CDA of micro-elements were able to discriminate 99.4% of the total variance. The first canonical function represented 92.4% variance, while the second canonical function represented 7.0% variance. The application of CDA to analyze four micro-elements results in 70.4% classification accuracy. Unfortunately, based on the mean of canonical variance, the first canonical function and the second canonical function were unable to distinguish all the geographical origin of the samples except the samples originated from Karangasem.

Further analysis of macro elements was deployed better to visualize the samples for the different region of origin. The CDA deployed to analyze five macro elements of magnesium (Mg), potassium (K), sodium (Na), calcium (Ca), and iron (Fe) is shown in Figure 4.

The *Test of Equality of Group Means* was deployed to determine the significance of macro elements to discriminate. Among five macro elements, calcium (Ca), sodium (Na), and potassium (K) were three macro elements that can be discriminate significantly (*p-value* < 0.05). The first two canonical functions obtained from CDA were able to discriminate 95.9% of the total variance. The first canonical function represented 71% variance, while the second canonical function represented 24.9% variance. The application of CDA to analyze five macro elements results in 88.9% classification accuracy.

Furthermore, the CDA of macro-elements was able to separate the samples into four groups. Based on the mean of canonical variance, the first canonical function and the second canonical function were able to distinguish all the samples' geographical origin except the samples that originated from Wonogiri and Gunungkidul. The elemental characteristics closeness between samples that originated from Wonogiri and Gunungkidul is thought to be since these two regions are geographically close together. Therefore, they have relatively the same environmental conditions at a certain level and affect the mineral content of cashew nuts.

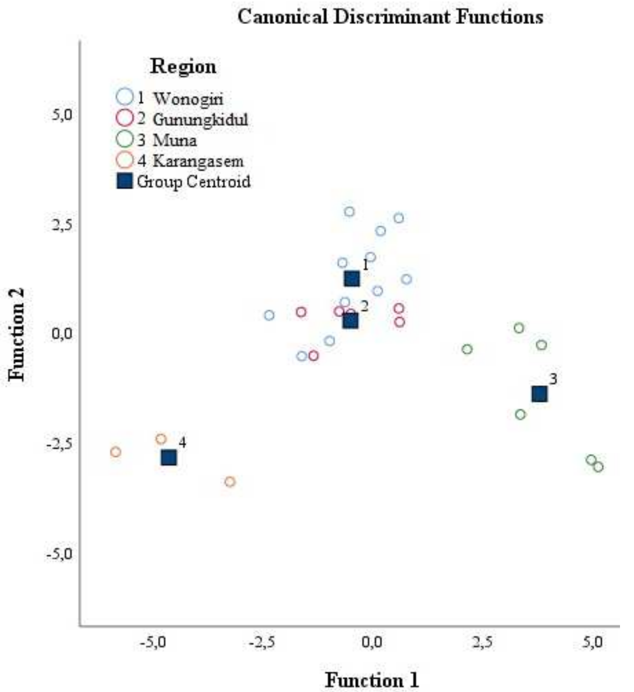

Fig. 4 Canonical Discriminant Analysis scatter plot based on Mg, K, Na, Ca, and Fe for cashew nuts samples

The samples' geographical origin discrimination using combination of micro and macro elements concentrations was also deployed. The CDA axes in two dimensions achieved by the analysis of copper (Cu), zinc (Zn), chromium (Cr), manganese (Mn), magnesium (Mg), potassium (K), calcium (Ca), sodium (Na), and iron (Fe) were shown in Figure 5.

The *Test of Equality of Group Means* was deployed to determine the significance of elements to discriminate. Among nine elements, sodium (Na), calcium (Ca), manganese (Mn), potassium (K), and zinc (Zn) were five elements that can be discriminate significantly (*p-value* < 0.05). The first two canonical functions achieved from Canonical Discriminant Analysis differentiated 96.4% of the total variance. The first canonical function represented 86.7% variance, while the second canonical function represented 9.7% variance. The application of CDA to analyze a combination of micro and macro elements results in 100% classification accuracy. Furthermore, CDA was able to separate the samples into four groups. Based on the mean of canonical variance, the first canonical function and the second canonical function were also able to distinguish all the samples' geographical origin except the samples that originated from Wonogiri and Gunungkidul.

To better visualize Wonogiri and Gunungkidul cashew nut samples, a combination of elemental profiles and chemical composition analysis was deployed. Total protein content was selected to represent the samples' chemical composition since the protein amount provides significant differentiation between Wonogiri and Gunungkidul samples (Tabel 3). The CDA axes in two dimensions achieved by analyzing the combination of elemental profiles and protein concentrations were shown in Figure 6.

The *Test of Equality of Group Means* was deployed to determine the significance of elements and chemical composition to discriminate. Among nine elements, sodium (Na), calcium (Ca), manganese (Mn), potassium (K), and zinc (Zn) were five elements that can be discriminate significantly (*p-value* < 0.05). Protein concentrations also gave significance (*p-value* < 0.05) on the discrimination. The first two canonical functions achieved from Canonical Discriminant Analysis were able to discriminate 94.9% of the total variance. The first canonical function represented 79.8% variance, while the second canonical function represented 15.1% variance. The application of CDA to analyze a combination of elements and protein concentrations results in 100% classification accuracy. Furthermore, Canonical Discriminant Analysis separated the samples into four groups and gave better visual separation for all samples. However, protein is a less suitable parameter to differentiate since its unstable nature during the storage and transportation process.

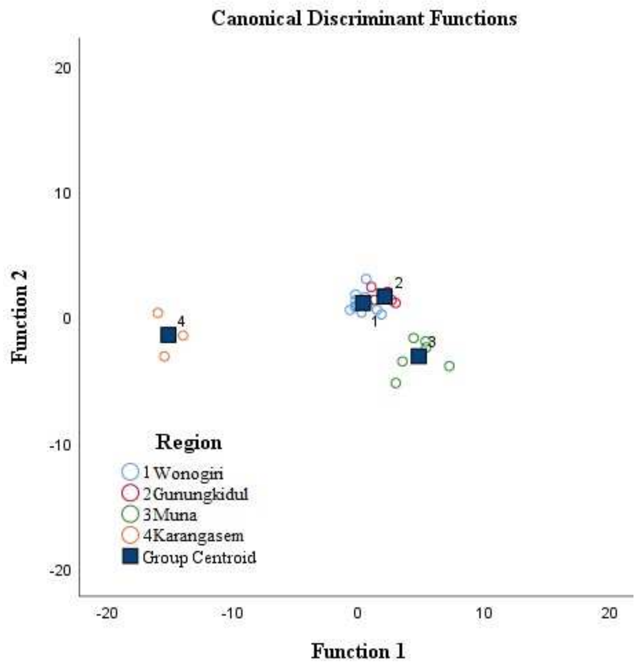

Fig. 5 CDA scatter plot based on a combination of macro and micro-elements for cashew nuts sample

Although there is a shortage of research focusing on the discrimination of cashew nuts origins using elemental profiles, some studies indicate that cashew nuts elemental profiles can become distinguished parameters. According to Nnorom and Ewuzie [32], sodium (Na), zinc (Zn), calcium (Ca), and manganese (Mn) concentrations gave promising results to separate Nigerian cashew nut samples. Another study found that potassium (K) also can be a potential descriptor [30]. The application of elemental profiles, especially sodium (Na), calcium (Ca), manganese (Mn), potassium (K), and zinc (Zn), also significantly discriminates against other food products. Manganese (Mn) and zinc (Zn) were used to separate snake fruit [12], while sodium (Na), manganese (Mn), and calcium (Ca) gave good visual on inter-continental coffee samples separation [43]. A study on rice's elemental profiles found that potassium (K) could be used as a parameter to discriminate rice that originated from Asian countries [14].

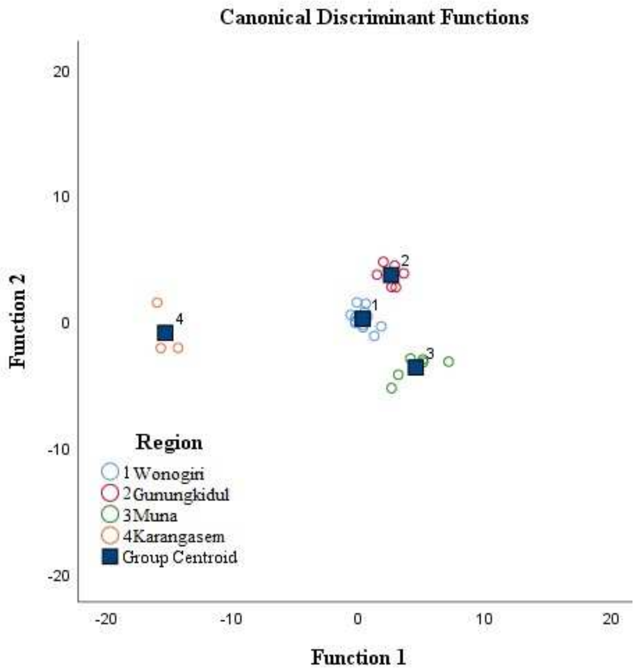

Fig. 6 CDA scatter plot based on a combination of elemental profiles and protein concentrations for cashew nut samples

IV. CONCLUSIONS

The concentrations of nine elements and five chemical compositions in 27 Indonesian cashew nut samples were analyzed in the present study. The result suggests that potassium (K) is the most abundant element in the cashew nuts, followed by magnesium (Mg) and calcium (Ca). At the same time, fat is the most abundant chemical composition in cashew nuts. Concentrations of potassium (K), magnesium (Mg), and calcium (Ca) revealed significant inter-regions differences. At the same time, zinc (Zn) and manganese (Mn) are two micro-elements that can significantly differentiate cashew nut samples' origin. Based on micro-elements concentrations, the application of Canonical Discriminant Analysis scatter plot was less significant to visualize the origin of Indonesian cashew nut samples. However, the CDA scatter plot's application based on macro elements, and CDA scatters plot based on the combination of both micro- and macroelements gave better results than the CDA scatter plot's application based on micro-elements. Besides, CDA scatter plot's application based on a combination of elemental profiles and protein concentration provided the best visual separation. Further study is necessary with a large number of samples for a comprehensive characterization of cashew nuts.

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