

Research

Chemical and sensory quality of citrus-flavored vegetable oils

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Abstract

Citrus-flavored vegetable oils (CFVO) demand has grown rapidly in the food industry due to increasing consumer demand for salads as a healthy food choice. Salad dressing has a distinctive taste from sour-tasting citrus that when added to salads to increase acceptance. This study primarily aimed to characterize antioxidant activity, total flavonoid content, and sensory quality by hedonic and organoleptic test between all unflavored oil and CFVO from three different vegetable oils (coconut oil (*Cocos nucifera* L.), palm oil (*Elaeis guineensis* L.), sesame oil (*Sesamum indicum* L.)) and three citrus (key lime (*Citrus aurantifolia*), kaffir lime (*Citrus hystrix*), and nasran (*Citrus ambylcarpa*)). One-Way ANOVA with post hoc Tukey were conducted to assess antioxidant and flavonoid differences. ANOVA with Tukey HSD and HSD, PCA and HCA, and a Spearman correlation analysis were conducted to assess the sensory qualities of citrus-flavored vegetable oils. There were different hedonic responses towards citrus in addition to the vegetable oils for each hedonic attribute. There is also a different response to the antioxidant and total flavonoids content of each treatment. The best formula according the multi-attribute decision using a compensatory model and additive weighting technique (MADCAW) score describes key lime (140%) flavored coconut oil as the best formula as having 56.58% antioxidant, 37.00 mg QE/100 g flavonoid and color liking 1.84, aroma liking 3.56, and taste liking 1.88. In conclusion, citrus-flavored vegetable oil has the potential to be a high-antioxidant vegetable oil with good acceptance by consumers.

Keywords Citrus · Vegetable oil · Key lime · Kaffir lime · Nasran · Coconut oil · Palm oil · Sesame oil · Chemical quality · Sensory quality

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1 Introduction

The increasing selection of healthier food products has led the food industry to innovate new food-related products. Flavored vegetable oil is one of the example [1], which is a type of vegetable oil infused with herbs, spices, or citrus to enhance its sensory qualities and health benefits [2]. The flavor profile of these oils is determined by the aromatic ingredients added, as they contribute to creating a unique taste and sensory experience [3].

Some underutilized oils such as coconut oil, palm oil and sesame oil have multiple health benefits and specific flavors. Coconut oil is important based on its medium-chain fatty acid content, such as lauric acid that beneficial for increasing metabolism and immunity [4]. Palm oil has bioactive compounds such as vitamin E which functions as an antioxidant, anti-aging, anticancer, and carotenoids with heart-protective and anticancer activities as well as phytosterol compounds which have cholesterol lowering and cardio-protective properties, squalene, and others [5, 6]. Sesame oil has a phenolic compound content of 7.90 mg GAE/100 gr, total flavonoids of 9.54 mg/100 gr and antioxidant activity of 42.3%. Sesame oil also contains sesamol with high bioavailability and antioxidant activity to prevent the oxidation of lipoproteins (LDL) in the blood and prevent the formation of plaque on the blood endothelial [7].

Citrus flavored vegetable oils (CFVO) are used as a salad dressing [8] that have grown rapidly in the food industry due to increasing consumer demand for salads as a healthy food choice. Salad dressing has a distinctive taste from sour-tasting citrus that, when added to salads increases acceptance.

Flavonoids are secondary metabolites that act as antioxidants in key lime (*Citrus aurantifolia*), where the highest concentration is found in the skin. Key lime also contains secondary metabolites such as carotenoids, phenolic acids, and triterpenoids [9]. Nasranan (*C. amblycarpa*) is rich in antioxidants and aromatic compounds such as alpha sinensal [10]. Kaffir lime (*C. hystrix*) is a fruit that has very high antioxidant activity and contains aromatic compounds such as terpinene-4-ol and limonene [11].

A previous study, which investigates citrus-flavored corn oil using 3%, 5%, 7% key lime, and sweet orange, showed that the higher the addition of citrus, the higher the bio-phenol value. In addition, sensory analysis results showed that corn oil added with key lime and sweet orange had higher values in terms of aroma, taste, and color [8].

To date, the characterization of CFVO was limited to single oil and single citrus variety combination such as olive oil [12, 13], corn oil [8, 14], and the citrus fruits used was limited to sweet lemon (*C. limetta*) [13], sweet oranges (*C. sinensis*) [13], bitter orange (*C. x aurantium*) [12, 14], lemon (*C. limon*) [12], and key lime (*C. aurantifolia* L.) [8]. Exotic oils such as sesame oil, palm oil, and coconut oil and exotic citruses such as key lime, nasranan, and kaffir lime were not explored. Moreover, there is a lack of assessment of nutrient, liking and flavor components in citrus-flavored vegetable oils from multiple oils and citruses. Because comprehensive comparisons of quality parameters from different CFVOs are not accessible, those interested along with consumers with specific quality needs may struggle to find a suitable CFVO.

This study primarily aimed to characterize antioxidant activity, total flavonoid content, and sensory quality in CFVO from different vegetable oils and citruses.

2 Materials and methods

2.1 Raw materials

The citrus used in this research are key lime, kaffir lime, and nasranan were purchased from local market in Semarang, Central Java, Indonesia and stored at 10 °C and used within five days after arrival. The collection of key lime (*Citrus aurantifolia*), kaffir lime (*Citrus hystrix*), and nasranan (*Citrus amblycarpa*) used in this study complied with local and national guidelines. The citrus was identified for the species and variety using a plant determination test at the Ecology and Biosystematic Laboratory of the Department of Biology, Universitas Diponegoro, Semarang, Indonesia. Citruses that have met the requirements of the type and species validity test then can be used as the research raw materials.

The vegetable oil used for the research includes coconut oil (Barco, PT. Barco, Indonesia), palm oil (Sania, PT Wilmar Cahaya Indonesia Tbk, Indonesia), and sesame oil (Roasted, ABC, PT Heinz ABC Indonesia, Indonesia).

2.2 Sample preparation

The citrus was weighed and washed thoroughly. The fruits are then dried with a paper towel and sliced into 4 pieces and the seed is removed because it gives a bitter taste. Fresh citrus fruit slices are soaked in 1% salt (NaCl) solution for 10 s to reduce surface microbes after cutting process and then rinsed with water and drained to dry for 20 min. The fruit

slices were then weighed and portioned according to the composition of the formulation (Table 1). For Q1 we used 60% citrus concentration by adding 60 g citrus into 100 g vegetable oil, Q2 100% concentration by adding 100 g citrus into 100 g vegetable oil, and Q3 140% concentration by adding 140 g citrus into 100 g vegetable oil. The concentrations of 60%, 100%, and 140% were determined based on an initial study that aimed to produce a CFVO formulation with an organoleptic citrus taste and aroma. The findings of our initial study showed that the taste and aroma of citrus were observed organoleptically started when using the 60% formulation, thus we picked it as the lowest concentration. We used greater concentrations (100% and 140%) to establish the correlation between the addition of citrus and the sensory quality of vegetable oils. Meanwhile, at lower concentrations (e.g. 20 and 40%), our panellists were unable to detect the citrus flavor we added, therefore the study's findings did not represent the effect of adding citrus on the sensory quality of vegetable oils.

The fruit slices then were crushed together with the oil using a hand blender for 5 min until homogenous. The mixtures then were centrifuged twice at 1107g for 10 min. The supernatant was extracted from the precipitate. The supernatant then was stored in a dark-colored bottle to prevent oxidation. The samples were produced in two repetitions on the same day. The samples were kept in a – 18 °C freezer until further use.

2.3 Organoleptic analysis

The organoleptic quality analysis was performed using descriptive and hedonic tests on 25 untrained panelists [15] from the Nutrition Science department, Universitas Diponegoro, Indonesia. All participants are women with age 19–23 years, and informed consent. The descriptive test was performed using 5 variables (oily flavor, citrus aroma, oily aroma, green color, and acidic flavor) expressed on a 5-point scale (1: "very weak"; 5: "very strong"). Then the hedonic test was conducted by evaluating the taste, aroma, and color overall on a 5-point scale. All samples served in the cup in room temperature. After taste each sample, all participants asked to drink plain water. Ethical clearance for this research has been published by the Bioethics Commission for the Medical/Health Research of the Faculty of Medicine, Sultan Agung Islamic University with number 116/IV/2022/Bioethics Commission. This quality test was a preliminary test, where the group of samples of each vegetable oil group that show the lowest descriptive organoleptic test and hedonic test results were not be analyzed further for the antioxidant activity and total flavonoid compounds.

2.4 Antioxidant activity

The antioxidant activity of CFVO was measured using the DPPH method. Additionally, we used Trolox for standard of antioxidant activity test. A methanol–water mixture (60:40) was used to extract all the phenolic compounds present in the oil matrix with a 1:10 ratio for 24 h [8]. One milliliter sample was added with 1 ml ethanol and 250 µl DPPH-ethanol solution. The solution is shaken using a vortex until homogeneous, then incubated in a dark place for 1 h, and then the absorbance of the remaining DPPH radicals is measured using a spectrophotometer (Spectroquant Prove 300, Merck KgaA, Germany) at a wavelength of 517 nm. The control solution consisted of 1000 µl ethanol and 250 µl DPPH-ethanol solution, whereas the blank solution consisted of 1000 µl sample and 1250 µl ethanol [16]. The test was done in triplicate. The percentage of elimination of the DPPH radical is calculated using the following formula:

Table 1 Formulation ratio of citrus-flavored vegetable oils (CFVO) (% citrus concentration)

Vegetable oil	Citrus	Control	Q1	Q2	Q3
Coconut	Key lime	0	60	100	140
	Kaffir lime	0	60	100	140
	Nasnaran	0	60	100	140
Palm oil	Key lime	0	60	100	140
	Kaffir lime	0	60	100	140
	Nasnaran	0	60	100	140
Sesame	Key lime	0	60	100	140
	Kaffir lime	0	60	100	140
	Nasnaran	0	60	100	140

Q1: 60% citrus concentration; Q2: 100% citrus concentration; Q3: 140% citrus concentration

$$\text{DPPH Radical Scavenging Activity} = \frac{A - B}{A} \times 100$$

A: the absorbance of the DPPH solution without the sample.

B: the absorbance of the DPPH solution with the sample.

2.5 Flavonoid content

The flavonoid content of the CFVO was measured using the colorimetric method [17]. Five g of sample was dissolved in 100 ml ethanol and centrifuged. A total of 1 ml of clear solution is then taken and added with 2 ml of 5% AlCl_3 solution. Furthermore, the solution is added with ethanol up to 10 ml and the absorbance is measured using a UV-vis spectrophotometer (Spectroquant Prove 300, Merck KgaA, Germany) at 420 nm. Quercetin was used to produce the calibration curves. Fifteen mg of quercetin powder in 100 ml of ethanol were used as the working solution. The analysis was done in duplicate and was expressed in mg quercetin equivalent (QE)/100 g.

2.6 Volatile composition analysis

The volatile organic compounds (VOCs) of CFVO were analyzed using headspace gas chromatography-mass spectrometry (GC-MS). Briefly, 0.1 g sample and 20 μl 1-hexanol (1 mg/ml in pentane) as internal standard were placed in a 10 ml vial. The headspace was set at 40 °C, loop temperature 80 °C, and transfer line temperature 130 °C, and the sample equilibration time was 10 min (G1888, Agilent Technologies, Santa Clara, CA, USA). GC-MS analysis was performed using an Agilent 7890A GC-5975C MS, equipped with DB-Wax column (30 m $\times$ 0.25 mm, 0.25 μm). VOCs were injected into the GC-MS system into injection port at 250 °C in a split mode (10:1). Helium was used as carrier gas at a flow rate of 32 cm/s. The GC oven was programmed from 40°C (held for 2 min) to 200 °C at 10°C/min, then isothermally held for 2 min. The MS ion source and interface were both programmed at 230°C, the electron impact ionization at 70 eV, and the acquisition range at m/z 33–450. Each compound was identified by comparison of the linear retention indices (RIs) from the calculation of a homologous series of n -alkanes (C7–C20), the MS patterns of the authentic standards, and the MS patterns of the peak compared to NIST08 library. The peak's weight intensity was adjusted according to the mass spectrometry (MS) response of the internal standard, and the concentration of the VOCs was denoted in $\mu\text{g}/100$ g. All analyses were carried out in triplicate.

2.7 Data analysis

2.7.1 Bivariate analysis

One-Way ANOVA followed by Tukey post hoc test using SPSS version 25 was done to determine the significant differences among the combination of citrus and vegetable oils. The p -value threshold used for determining significance in all tests was set at $p < 0.05$.

2.7.2 Multivariate analysis

ANOVA analysis followed by Tukey Honest Significant Differences post hoc test using R software was done to determine the significance of the oils and citrus used in the citrus-flavored vegetable oils. Tukey HSD function within R was used to compute the significance of the oils and citrus. On the other hand, HSD test [18] function within the agricolae package was used to compute the significance of the interaction between oils and citrus.

A multivariate visual graph of the sensory quality of citrus-flavored vegetable oils was constructed using principal component analysis (PCA) and hierarchical cluster analysis (HCA) plots using R software. Both multivariate analysis was based on a mean-centered structure, and the HCA plot was obtained using Euclidean distance and complete linking. Clusters were obtained using a 0.900 similarity index and produced using gg dendrogram package [19].

A correlation matrix of the organoleptic attributes was analyzed using Spearman method by R Studio 2023.09.1 Build 494, R version 4.3.2. A correlation matrix graph was produced using corplot package [20].

2.7.3 Formula selection

The best formulation was chosen based on Multi-attribute decision using a compensatory model and additive weighting technique (MADCAW) [21] with antioxidant activity as the priority among other quality attributes. The best formulation was chosen based on the best value from the calculation of the rating of each variable and the score.

3 Results and discussion

3.1 Organoleptic analysis

3.1.1 Descriptive test

Based on the descriptive test, the oily flavor of the CFVO decreased significantly compared to the control for all the oils and citrus combinations used, as shown in Fig. 1a. Oily flavor could be contributed by non-volatile compounds in the oil [22], furthermore [23] mentioned that oily flavor was contributed by long-chain aldehydes, alcohols and ketones. The addition of citrus significantly decreases the oily flavor, which could be attributed to the fresh sensation of citrus in the oil. Some citrusy flavor of citrus fruit contributed by citric acid, ascorbic acid, isocitric acid, quinic acid, uric acid, decanal, and octanal [24].

Oily aroma of the CFVO was decreased significantly compared to the control for coconut and sesame oils and citrus combinations, but not for palm oil. The palm oil control has low oily aroma attributes, as observed in Fig. 1c. This property could relate to the processing technology involved in palm oil manufacturing. Palm oil was gone through an intense deodorization technique using high vacuum and temperature, which strips out all volatile compounds responsible for the oily aroma [25].

A different case was found for coconut and sesame oil. Both oils were produced by a milder process thus retain the volatile compounds in the oil which was observed in Fig. 1c. Coconut oil has a distinctive coconut aroma caused by the content of δ -octalactone compounds [26]. Coconut oil is mostly derived by the dry process, in which dried coconut meat (copra) is crushed using an expeller. This process recovers the majority of the oil, although some oil may remain in the residual material, which can be removed further with solvents. Fresh coconut kernel is utilized in the wet process instead of copra, and the resulting oil does not require refining. Sesame oil is derived by first cleaning and cooking the seeds, and then using an expeller. The crude sesame oil is then processed numerous times to make it suitable for use as salad oil. The remaining sesame cake following the extraction still contains oil that may be recovered further [27].

Furthermore, sesame oil was well known for its aromatic oils that elevate the flavors of the food sautéed in the sesame oil. Sesame oil can be produced by cold press method and roasted method. Those processing methods produced a distinctive aroma profile. Important attributes of roasted sesame oil including aroma profile of roasted sesame seed, caramel like, smoked, burnt, and popcorn like. Those aroma profiles were contributed by 2,5-dimethylpyrazine, 2-methylpyrazine, and trimethylpyrazine which contributed to most of the roasted sesame oil aroma active compounds [28].

Addition of citrus was able to suppress oily aroma of coconut oil, but not for sesame oil. Song and Liu [23] mentioned that oily flavor was contributed by long-chain aldehydes, which could be present in large quantity, and was not significantly masked by the citrus even at a highest concentration. An interesting case was found in palm oil which was not affected by the addition of citrus. Initially, as mentioned before, palm oil does not have a noticeable oily aroma, and as citrus was introduced, even there was a slight increase of the oily aroma. This increase was contributed by the hydrolysis of the unsaturated fatty acid in the palm oil. Fatty acid hydrolysis is the mechanism that decomposes triglycerides into glycerol and its constituent fatty acids. In the lipid oxidation process, free fatty acids are more prone to oxidation compared to esterified fatty acids. These free fatty acids accelerate the decomposition of hydroperoxides and trigger the breakdown of triglycerides into mono- and di-glycerides. The initial products of oxidation are peroxides and hydroperoxides, which can propagate and ultimately break down into secondary oxidation products such as minor organic acids, aldehydes, and ketones [29].

Citrus aroma was increased as soon as the citrus was introduced in all of the oils (Fig. 1b). However, there was a quite notable result from the kaffir lime flavored sesame oil. This combination did not produce the same level compared to other combinations. This could be contributed by the strong aroma of sesame oil which suppressed the kaffir lime aroma. Kaffir lime aroma was contributed by camphene (woody), α -pinene (herbal), α -terpinene (woody), β -pinene (herbal), γ -terpinene (terpenic), limonene (citrus) [30].

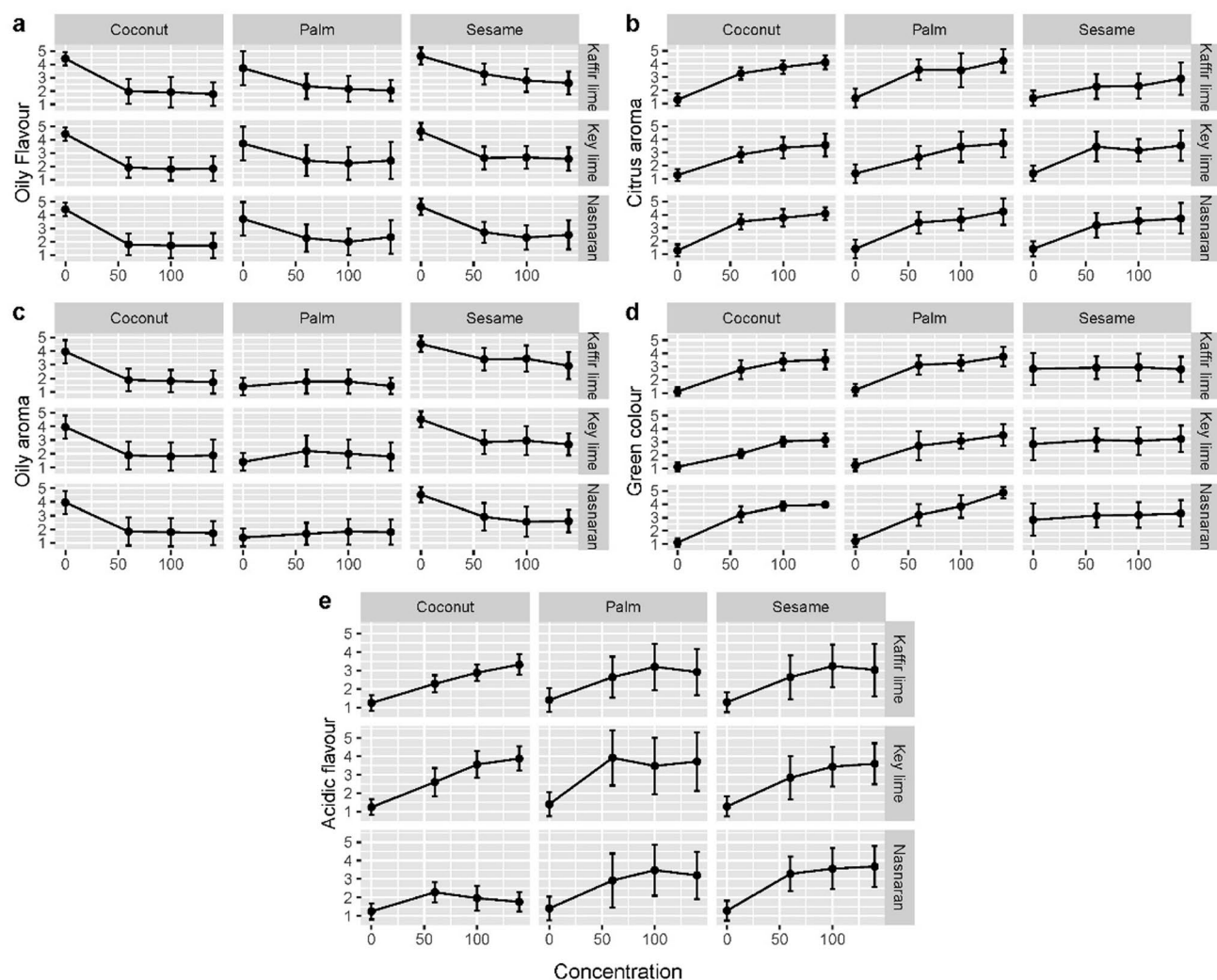


Fig. 1 Descriptive sensory value of citrus flavored vegetable oils for (a) oily flavor, (b) citrus aroma, (c) oily aroma, (d) green color, e acidic flavor

Green color was the key identification for CFVO. This green color comes from the chlorophyll compounds in the citrus skin which then dissolve into oil, so it increases the greenish color [31]. The green color increase was observed in both citrus flavored coconut and palm oil, but not the citrus flavored sesame oil. Because initially coconut oil and palm oil were colorless and yellowish, respectively, whilst coconut oil is colorless because of the absence of the natural pigment in the fruit itself. On the other hand palm oil is contains beta carotene that gives attractive bright yellowish color [32]. Furthermore, sesame oil has brown color come from the oil production. The sesame were roasted and the browning substances that appear after roasting are produced by non-enzymatic Maillard reactions between reducing sugars and free amino acids [33].

The acidic flavor intensity of CFVO was generally linier (Fig. 1e). The increase in citrus concentrations increases the acidic flavor except for nasnaran flavored coconut oil which is decreasing after increasing at 60%. This could be influenced by the acid flavor in the nasnaran was not strong enough to overshadow the oily flavor of the coconut oil. The acidic flavor also becoming marker for citrus flavored sesame oil, as can be observed in Fig. 4b.

3.1.2 Hedonic test

The addition of citrus to vegetable oils has a variety of responds regarding of color likeness. Citrus flavored coconut oil has a slightly higher likeness in color compared to the control as can be observed in Fig. 2a. Regardless of the effect of the citrus addition, the likeness toward coconut oil was lowest compared to other oils, seems consumer likes colored

oils rather than colorless oil. Furthermore, palm oil control has the highest liking in color compared to other oils. This result proved that consumers liked the yellow golden color of palm oil compared to colorless oil or brownish color of sesame oil. Despite the liking to the palm oil control, the addition of citrus directly reduces the liking of their color. Nevertheless, the green color intensity has negative correlation towards liking of the color as can be observed in Fig. 3. A different case for sesame oil color liking, there was no effect on the addition of citrus. This could relate to the brownish color of the sesame oil which subdue of green color of the citrus. This data also indicated by the green color intensity perceived by the consumer as described in Fig. 1d.

Aroma liking of CFVO was increased after citrus addition compared to the control oil for coconut and palm oil, but not for sesame oil as described in Fig. 2b. Initially coconut oil has a dislike aroma, but after citrus addition the liking of aroma becoming neutral. A similar case for palm oil, but initially palm oil was already neutral by consumers and the addition of citrus only slightly increased the liking towards color. A different case was found in sesame oil, Initially the liking of sesame oil was liked, and was not changed after citrus addition, even though the citrus aroma increased, and oily aroma decreased, the liking of the aroma of the sesame oil was slightly decreased for kaffir lime flavored sesame oil, but not changed at all for nasranan and fluctuated with key lime.

The taste liking among vegetable oils also varies and does not line up with aroma liking (Fig. 2c). Coconut oil initially did not have a liked taste, but then added 60% of citrus becoming neutral, but then the taste liking was decreasing as the concentration increased. This change could be attributed to the acidic flavor that was introduced by the citrus addition. Citrus flavored palm and sesame oil have the same taste behavior as they are decreasing becoming disliked as the increase of citrus addition. Additionally, citrus contain naringin which at 20 ppm considered bitter [34].

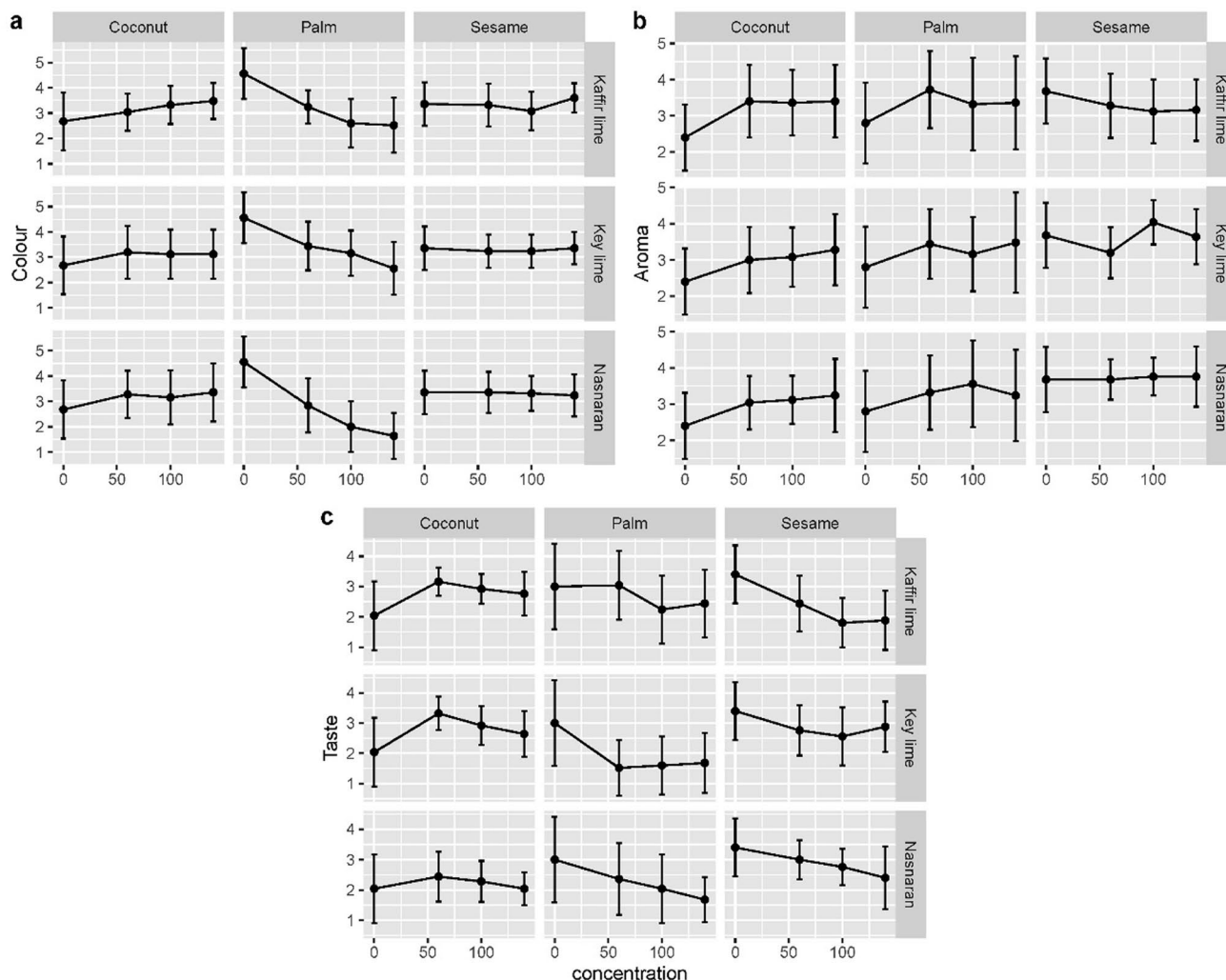


Fig. 2 Hedonic value of citrus-flavored vegetable oils for (a) color, (b) aroma, (c) taste

Fig. 3 Correlation plot among sensory attributes

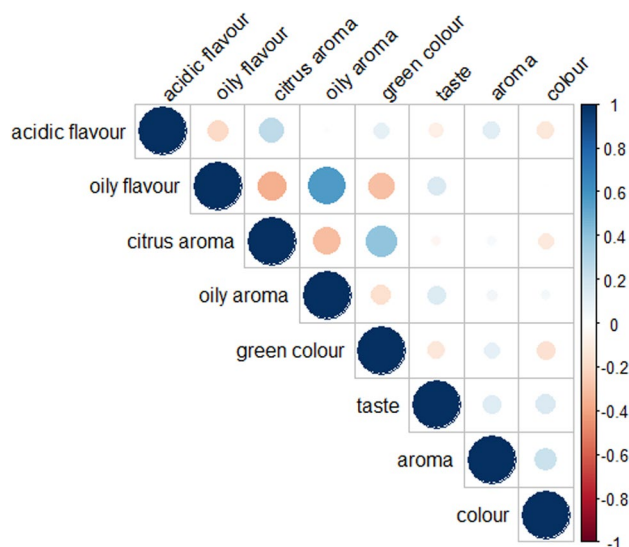


Figure 3 shows several key relationships between the sensory attributes of CFVO. First, an increase in acidic flavor correlates to an increase in citrus fragrance. This shows that these characteristics are closely connected. Similarly, there is a significant association between oily flavor and oily fragrance, showing that these two characteristics are inextricably related. Furthermore, taste is positively correlated with both acidic and oily tastes, indicating that these qualities have a major influence on the overall taste of the CFVO. A previous study on the sensory evaluation of mayonnaise made with virgin coconut oil found that panelists preferred mayonnaise characterized by a fresh taste with a hint of acidity [35]. Furthermore, the circles in the matrix that show correlations between color attribute and other qualities are not particularly large, indicating weaker relationships. However, the intensity of the green color is positively correlated with citrus aroma, indicating that as the green color intensifies, the citrus aroma tends to increase as well. This association implies that the presence of green color may improve the perception of citrus fragrance, and vice versa.

3.1.3 Antioxidant and total flavonoid

Antioxidant content of CFVO was different among the oils. Coconut and sesame oil has similar increase as the citrus concentration increased as shown in Table 2. Citruses contain multiple compounds that have antioxidant activities. Nasnaran contains essential oils with a fairly high content of volatile compounds including α -sinensal, α -limonene, α -farnesene, benzoic acid, β -bisabolene, β -citronellal, betacis-ocimene, β -myrcene, β -pinene, citronellol, 2-methoxy-4-vinylphenol, 2,3-dihydro-3,5-dihydroxy-6-methyl-4 h- pyran-4-one and sabinen [36]. Some volatile compounds such as α -limonene, β -myrcene, and β -pinene are known for their antioxidant activity [37].

However, palm oil seems to respond to citruses addition slower compared to coconut and sesame oil. The fatty acid composition of the vegetable oils may play an important factor. Palm oil was not able to fully dissolve the high antioxidant compounds of citruses. Coconut oil was known for high lauric acid content (C12:0, 48%), meanwhile palm oil contain palmitic acid (C16:0, 41%) and oleic acid (C16:1, 31%), meanwhile sesame oil consisted of oleic acid (C16:1, 41%), and linoleic acid (C18:2, 43%) [38].

The interesting part was the flavonoid content of the CFVO. Only coconut was able to pick flavonoid compounds. Palm oil responds to the citrus addition was very slow, on the other hand sesame flavonoid concentration was decreased. The medium chain fatty acids that are abundant in the coconut oil may play an important role here.

Based on PCA analysis, we can find that flavonoid and antioxidant were the key determinant for oil base of the CFVO. Flavonoid was the key component for coconut oil where the antioxidant activity was the key component for sesame oil as can be observed on Fig. 4a. Furthermore, Fig. 4a shown that sesame oil shows high antioxidant content, while coconut oil shows higher flavonoid content. Additionally, on Fig. 4b coconut and palm oil samples are more spread out along both PC1 and PC2, indicating a variety of sensory attributes, while sesame oil samples' sensory attributes tend to cluster towards the positive side of PC1. For instance, sesame oil tends to have a distinct sensory profile characterized by acidic flavour and oily aroma.

Table 2 Antioxidant and flavonoids of citrus-flavored vegetable oils (CFVO)

Oil	Citrus	Citrus Concentration (%)	Antioxidant (% inhibition)	Flavonoid mg QE/100 g
Coconut	Kaffir lime	60	19.24±0.14 ^{ab}	25.50±0.71 ^a
Coconut	Kaffir lime	100	24.28±0.13 ^c	34.00±1.41 ^b
Coconut	Kaffir lime	140	59.48±0.13 ^d	37.50±0.71 ^c
Coconut	Key lime	60	16.25±0.28 ^{ae}	23.00±1.41 ^d
Coconut	Key lime	100	23.31±0.13 ^{bc}	30.50±2.12 ^e
Coconut	Key lime	140	56.58±0.13 ^d	37.00±1.41 ^c
Coconut	Control	0	12.28±0.14 ^{ef}	18.00±1.41 ^f
Palm	Kaffir lime	60	5.92±1.41 ^{gh}	0.96±0.11 ^{gh}
Palm	Kaffir lime	100	12.10±0.97 ^{ef}	1.41±0.10 ^{gh}
Palm	Kaffir lime	140	19.21±1.43 ^{ab}	1.97±0.07 ^g
Palm	Nasnaran	60	8.80±0.50 ^{fg}	1.09±0.13 ^{gh}
Palm	Nasnaran	100	18.05±1.07 ^a	2.10±0.13 ^g
Palm	Nasnaran	140	25.77±1.27 ^c	2.54±0.12 ^g
Palm	Control	0	1.88±0.40 ^h	0.31±0.02 ^h
Sesame	Nasnaran	60	26.60±2.57 ^c	5.70±1.21 ^{ij}
Sesame	Nasnaran	100	38.69±1.63 ⁱ	5.17±0.16 ^{ij}
Sesame	Nasnaran	140	75.57±2.91 ^j	4.48±0.13 ⁱ
Sesame	Key lime	60	24.47±2.64 ^c	5.15±0.17 ^{ij}
Sesame	Key lime	100	36.98±1.31 ⁱ	6.29±0.38 ^{ij}
Sesame	Key lime	140	58.55±2.15 ^d	4.80±0.43 ^{ij}
Sesame	Control	0	23.65±3.60 ^c	8.30±0.23 ^{jk}

Different superscripts (^{a-k}) within the same column indicate significant differences by One-Way ANOVA followed by Tukey post hoc test ($p < 0.05$)

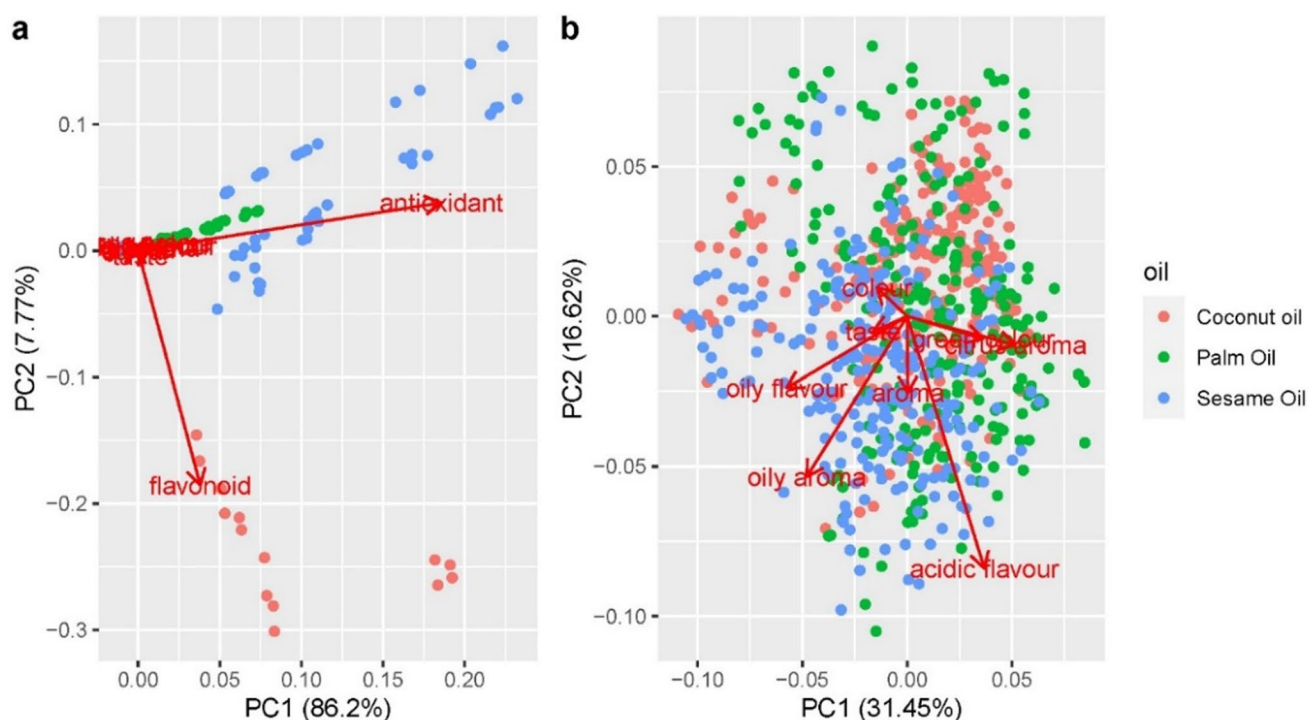


Fig. 4 PCA analysis of **a** Sensory properties (colour, taste, aroma, oily flavour, oily aroma, green colour, citrus aroma, acidic flavour), antioxidant activities and flavonoid content of citrus-flavored vegetable oils; **b** Sensory properties of citrus-flavored vegetable oils

3.1.4 Total volatile organic components (VOCs)

Characteristics of the aroma in CFVO can be determined by the composition of their Volatile Organic Compounds (VOCs), as these compounds can be recognized by our sense of smell. Oily aroma that identified during descriptive test (Fig. 1c) was confirmed present in the Total VOCs of the control at a very low concentration (Fig. 5). With sesame was the highest among other oils. However, after citrus was introduced, the total VOCs was increased significantly.

Oil types have a significant effect on the Total VOCs in the CFVO. Overall CFVO produced using sesame oil have a significant higher Total VOCs compared to other oils. Furthermore, overall CFVO produced using coconut oil have a not significant higher Total VOCs compared to palm oil. This difference could contributed to the polarity of the oils [39].

The main fatty acid in coconut oil is lauric and myristic acid [40]. Those fatty acids are short, strait and saturated, and make coconut oil more polar oil [39]. On the other hand, palm oil and sesame oil have mono and polyunsaturated fatty acid as their main fatty acid [41, 42], and make them more non polar oil [39]. This polarity difference seems to influence the total VOCs in the CFVO produced with sesame and coconut oil rather than with the palm oil. Sesame oil significantly extracted more total VOCs compared to the coconut oil citrus concentration. Furthermore, sesame oil significantly had more total VOCs compared to other vegetables oil because it is a non-refined oil other than filtering that keep their odor distinct [43].

CFVO produced with kaffir lime and nasranan have a significant higher total VOCs compared to key lime. Key lime's fresh fragrant citrus aroma was common to be use as a flavoring material [44]. However, this low total VOCs encourage consumers to use more CFVO with key lime compared to CFVO with kaffir lime and nasranan to get a same aroma strength. On the other hand, kaffir lime was used as condiment because of its strong fragrance [45]. The highest total VCOs was CFVO using kaffir lime and sesame seed, but the total VOCs was not different from CFVO produced using coconut and sesame oil with kaffir lime and nasranan.

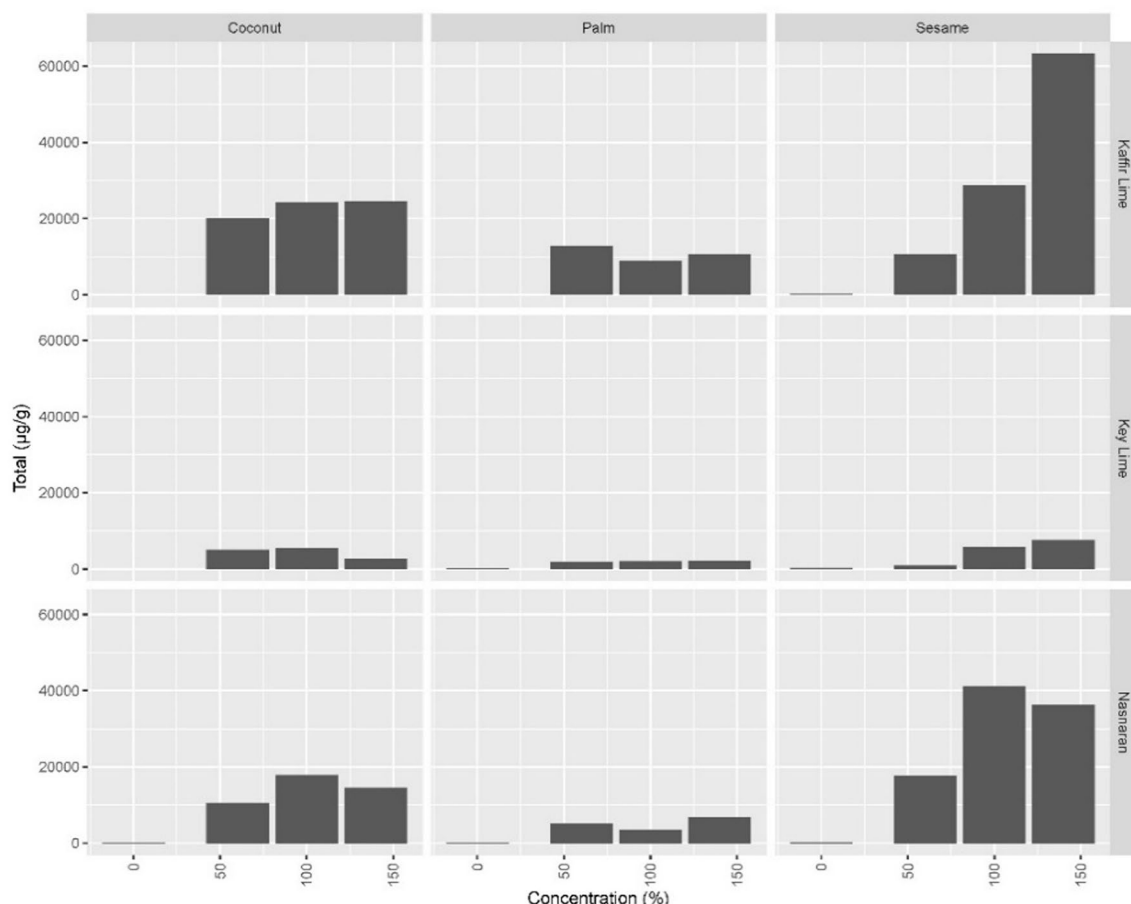


Fig. 5 Total volatile organic components (VOCs) of citrus-flavored vegetable oils

3.1.5 Formula selection

Multi-attribute quality combined by multiple product variety made product development becoming complex process and could produce a bias. Multi-attribute decision using a compensatory model and additive weighting technique (MADCAW) [21] was employed to pick the best product based on the selected attributes. Selected attributes including antioxidant, total flavonoid, liking to color, aroma, and taste, with the weight was respectively as listed as described in Table 3. The best product was key lime (140%) flavored coconut oil as having $56.58 \pm 0.13\%$ antioxidant, 37.00 ± 1.41 mg QE/100 g flavonoid, and color liking 1.84 ± 0.94 , aroma liking 3.56 ± 0.87 , and taste liking 1.88 ± 1.17 .

The best formula may not be optimal in other parameters excluded in the MADCAW. Another technique to choose the product was based on the similarity. In this case is the descriptive test. The average of the descriptive test results was calculated for HCA (Hierarchical Cluster Analysis) [46]. The HCA produced 14 groups from 30 samples as can be observed in Fig. 6. Each oil control was individual group. The best formula key lime (140%) flavored coconut oil was the same group of key lime (100%) flavored coconut oil, key lime (100%) flavored palm oil, key lime (140%) flavored palm oil, and nasnaran (100%) flavored palm oil. This method is also beneficial when the specific ingredients was not available and need to deliver the product quickly.

4 Conclusion

Antioxidant activity, total flavonoid content, and sensory quality in CFVO from three vegetable oils and three citruses have been characterized. There were different hedonic responses towards citruses in addition to the vegetable oils for each hedonic attribute. There is also a different response to the antioxidant and total flavonoids content of each treatment. MADCAW score describe key lime (140%) flavored coconut oil as the best formula as having $56.58 \pm 0.13\%$ antioxidant, 37.00 ± 1.41 mg QE/100 g flavonoid and color liking 1.84 ± 0.94 , aroma liking 3.56 ± 0.87 , and taste liking 1.88 ± 1.17 . This study indicates that the addition of citrus can improve sensory (color, taste, aroma) as well as antioxidant properties and

Table 3 Score of Multi-attribute decision using a compensatory model and additive weighting technique (MADCAW) of the citrus flavored vegetable oils (CFVO)

Sample			Score					Total score	
Oil	Citrus	Conc. (%)	Antiox	Flav	Color	Aroma	Taste		
Coconut	Kaffir Lime	100	0.10	0.24	0.01	0.11	0.01	0.47	
		140	0.26	0.27	0.00	0.13	0.01	0.66	
		60	0.08	0.18	0.01	0.09	0.01	0.37	
	Key lime	100	0.10	0.22	0.00	0.09	0.01	0.42	
		140	0.25	0.26	0.01	0.10	0.01	0.63	
		60	0.06	0.16	0.01	0.07	0.01	0.32	
	Control	Control	0.05	0.13	0.19	0.00	0.05	0.41	
	Control	Control	0.00	0.00	0.14	0.01	0.00	0.14	
	Kaffir Lime	100	0.05	0.01	0.03	0.10	0.01	0.19	
Palm		140	0.08	0.01	0.02	0.13	0.00	0.24	
		60	0.02	0.00	0.04	0.10	0.01	0.18	
		Nasnaran	100	0.07	0.01	0.02	0.11	0.01	0.22
		140	0.11	0.02	0.04	0.13	0.01	0.31	
		60	0.03	0.01	0.04	0.10	0.01	0.17	
		Control	Control	0.10	0.06	0.20	0.01	0.07	0.43
	Sesame	Nasnaran	100	0.17	0.03	0.04	0.10	0.02	0.37
			140	0.33	0.03	0.05	0.11	0.03	0.55
			60	0.11	0.04	0.07	0.09	0.03	0.34
Key lime		100	0.16	0.04	0.06	0.08	0.03	0.38	
		140	0.26	0.03	0.06	0.10	0.03	0.47	
		60	0.10	0.03	0.06	0.10	0.03	0.33	
Weight		5	5	4	3	2	1		
Norm. w		0,33	0.33	0.27	0.20	0.13	0.07		

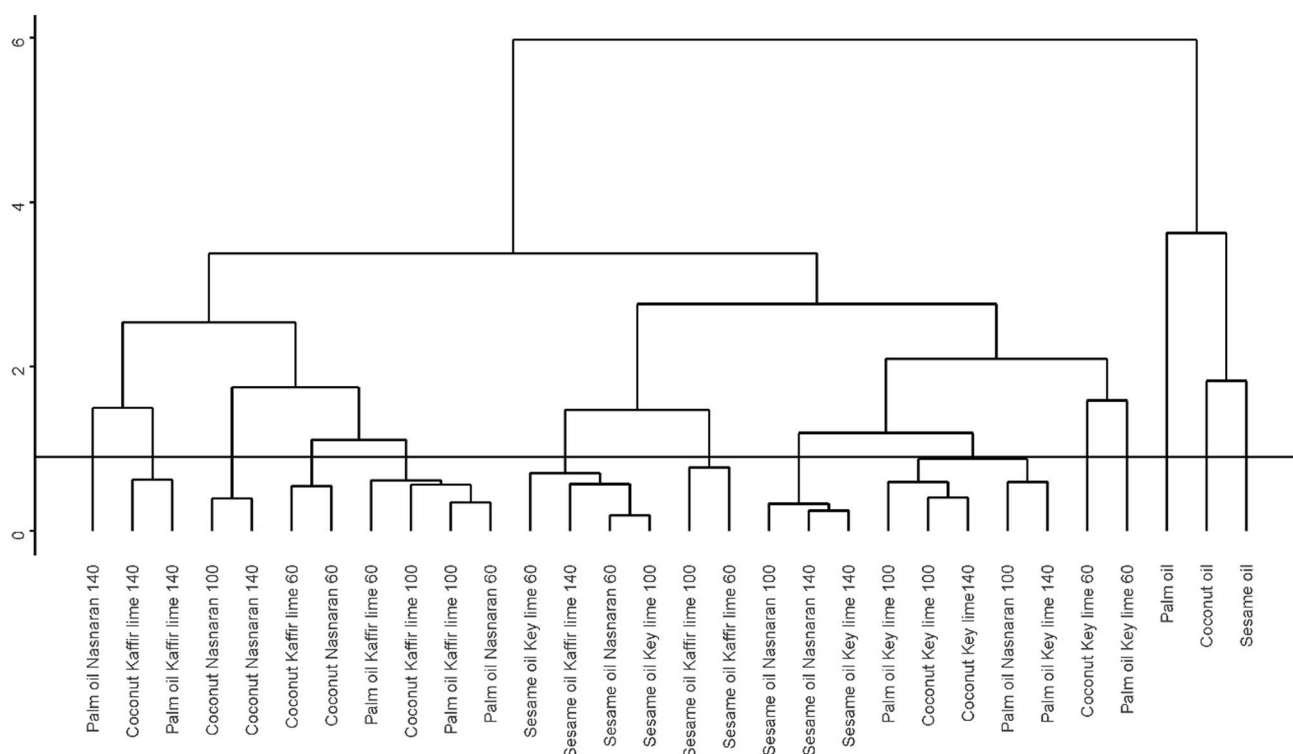


Fig. 6 HCA analysis of the Citrus-Flavored Vegetable Oils (CFVO) based on the descriptive sensory test

flavonoid of vegetable oil. Thus, CFVO, especially the best treatment (140%), has potential for being high antioxidant vegetable oil with good acceptance for consumers.

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Authors' contributions Conceptualization, F.A. and Y.A.; methodology, F.A., A.R., A.K. and Y.A.; software, F.A.; validation, F.A., R.P., H.S.W.; formal analysis, R.A., D.R.S., A.P., A.R., A.K.; investigation, R.A., D.R.S., A.P.; data curation, F.A., A.M.A.; writing—original draft preparation, F.A., A.M.A., R.A., D.R.S., A.P.; writing—review and editing, F.A., Y.A., A.M.A., D.N.A., G.A., R.A., D.R.S., A.P., R.P., H.S.W., A.R., A.K.; visualization, F.A.; supervision, F.A., D.N.A., G.A., R.P., H.S.W.; project administration, F.A.; funding acquisition, F.A., D.N.A., G.A. All authors have read and agreed to the published version of the manuscript.

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Data availability The raw data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher.

Code availability Not applicable.

Declarations

Competing interests The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential competing of interest.

Research involving human participants and informed consent The organoleptic studies involving human participants were reviewed and approved by the Bioethics Commission for the Medical/Health Research of the Faculty of Medicine, Sultan Agung Islamic University with number 116/IV/2022/Bioethics Commission. The participants provided their written informed consent to participate in this study. The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments.

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