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Research Article
Physicochemical, Fatty Acid and Antioxidant Properties of Passion Fruit (*Passiflora* Species) Seed Oil

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Abstract

Background and Objective: The passion fruit industry uses half of the fruit mass for juice extraction, while the rest represents an agricultural by-product that consists of rinds and seeds. Generally, the seeds are disposed of after being crushed, causing a substantial burden on the environment. Thus, efforts have been made to utilize the seeds for useful resources. This study focused on the physicochemical characteristics, fatty acid and antioxidant properties of seed oil extracted from three *Passiflora* species [*P. edulis* Sims (Purple), *P. quadrangularis* and *P. maliformis*]. **Materials and Methods:** *Passiflora* seed oil was extracted using petroleum ether as a solvent and analysed for its physicochemical properties: refractive index, specific gravity, iodine value, saponification value, non-saponification matter, acid value, peroxide value and free fatty acid content. The fatty acid composition and antioxidant properties were also analysed. **Results:** *Passiflora* seeds were rich in oil content, yielding 24-30%. The *Passiflora* seed oil also possessed high values of iodine (124.67±0.67-131.00±0.58 g I_2 100 g^{-1}) and peroxide (1.43±0.12-3.23±0.12 meq kg^{-1}) similar to other edible seed oils, e.g., sunflower. The seed oil contained essential fatty acids with a higher proportion of unsaturated fatty acids (>80%), mostly comprising linoleic and oleic acid. *Passiflora edulis* (Purple) seed oil had a comparatively higher total phenolic content (570.74±0.78 mg kg^{-1}) and stronger antioxidant activity (33.63±1.46 mg mL^{-1}). Based on principle component analysis (PCA), the biplot generated showed that *Passiflora* seed oils possessed characteristics similar to those of sunflower and soybean oils. **Conclusion:** The present findings revealed that the oil of *Passiflora* seeds, an agro by-product, is valuable and can be extracted for nutraceutical and pharmaceutical uses.

Key words: Fatty acids, iodine, *Passiflora* seeds, peroxide, phenolic content, seed oils

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Passiflora plants, generally known as passion fruit plants, are extensively grown in tropical and sub-tropical regions of the world. More than 500 species have been identified in this genus and most are distributed throughout Central and South America[1]. The world production of passion fruit ranges from approximately 1.05 million MTs to 1.27 million MTs, with Brazil as the largest producer and consumer of passion fruit in the world. In Malaysia, passion fruit plants are cultivated on a small scale due to the prevalence of suitable growing conditions[2]. The increasing demand for passion fruits in the local market provides income earning opportunities for local growers and farmers.

Passiflora plants have been cultivated for their edible fruits, ornamental flowers and pharmaceutical uses. The fruit has a soft to firm juicy interior filled with numerous seeds. Passion fruit enters international trade in the form of juice[3]. All passion fruit plant parts are potentially valued for different uses, giving them importance beyond that of their fruits, which are processed as juice and other products[2]. It is estimated that the juice production industry uses approximately half of the fruit's mass, while the rest represents agricultural by-products that consist of rinds and seeds[4-6]. Studies have been conducted and revealed that seeds of *P. edulis* Sims and *P. edulis* f. *flavicarpa* are edible and rich in oil but are generally disposed of after being crushed, which causes a substantial burden to the environment[7].

Various efforts have been undertaken to utilize these disposed products and thereby avoid disposal problems. Studies by Chau and Huang[7], Ramaiya *et al.*[8], Chumjai and Tippayawong[9], Malacrida and Jorge[10] and Liu *et al.*[11] have explored the usefulness of *Passiflora* seeds and have shown considerable promise. *Passiflora* seed oils could be utilized for various applications in the edible food, pharmaceutical, chemical, cosmetic and detergent industries, which would reduce the agro by-products generated by the passion fruit juice processing industry. A study by Chumjai and Tippayawong[9] revealed that passion fruit seed oil has the potential to be used as a biodiesel feedstock.

Considering the above review of the seeds, agro waste could be converted or processed to other useful resources such as oil, which could reduce agricultural waste and serve as a source of additional income[12]. Furthermore, the continued increase in the world population and global oil consumption has resulted in an increase in the price of oil. The search for alternative oil sources is critical[13]. Thus, assessing *Passiflora* seed oil properties from various species contributes to the acquisition of knowledge to optimize the use of these raw materials for edible or industrial purposes. Studies have examined the seed oil properties of purple and yellow passion fruits but little information is available on the characteristics of other *Passiflora* species, including the phenolic content and antioxidant capacities of *Passiflora* seed oils. Therefore, the aim of this study was to evaluate the physicochemical properties, fatty acid composition and antioxidant activities of oils extracted from the seeds of *P. edulis* (Purple), *P. quadrangularis* and *P. maliformis* that can be beneficial to the development of nutraceutical and pharmaceutical uses of agro by-products. This study will help researchers uncover the potential uses of other *Passiflora* species seed oils compared to the well-known purple and yellow passion fruits.

MATERIALS AND METHODS

Experimental site and sample preparation: Mature passion fruits were harvested randomly for *P. edulis* (Purple), *P. quadrangularis* and *P. maliformis* from the passion fruit farm on Universiti Putra Malaysia Bintulu Sarawak Campus, Bintulu (N 03°12.45' and E 113°4.68'), Sarawak at different harvesting periods. The fruits were brought to the laboratory and immediately inspected and cleaned. The seeds were mechanically removed from the fruits, washed with distilled water and dried at room temperature for a week. Approximately 2 kg of seeds from each *Passiflora* species were collected from fruits, homogenized into a fine meal including the shell using a manual grinding machine and stored in an airtight container at 4°C for subsequent analyses.

Seed oil extraction: *Passiflora* seed oil was extracted using the Soxtec solvent extraction technique with petroleum ether as the solvent. Five grams of the finely ground seed meal was weighed into six separate reservoirs. Seventy millilitres of petroleum ether (boiling point ranging 40-60°C) was added to each reservoir. After extraction, the solvent was evaporated manually. The extracted oil was then kept in a glass bottle that was sealed and stored at 4°C prior to analysis.

Physicochemical properties of seed oil: The following physicochemical properties of seed oils were determined. For the physical characteristics, the state and colour of the oil were noted by visual inspection. The refractive index (RI; 40°C) was determined at room temperature using the Abbe refractometer[14]. The specific gravity (SG) was also determined for the extracted oil. The chemical properties, including iodine value (IV), saponification value (SV), non-saponification matter (NSM), acid value (AV), peroxide value (PV) and free fatty acid

(FFA, % in oleic acid), were determined using the standard protocols of AOCS[14]. Each oil sample was analysed in triplicate.

Fatty acids analysis of the seed oil: The fatty acid composition of the three *Passiflora* seed oils was determined by their fatty acid methyl esters (FAME) using a gas chromatography capillary column. The extracted oil was prepared according to the AOAC[15] method prior to determination of fatty acid composition. The system used was equipped with a flame ionization detector, injector and autosampler. The carrier gas was hydrogen. The condition and setup for the determination of the FAME content with gas chromatography (GC) was performed according to the protocol by Nzikou *et al.*[16]. The fatty acid methyl ester peaks were identified by comparing their retention time with standards. The percent relative fatty acid was calculated based on the peak area of a fatty acid component and the total peak area of all fatty acids in an oil sample.

Determination of total phenolic content (TPC): TPC was determined using the Folin-Ciocalteu method as described by Malacrida and Jorge[10]. One gram of oil was weighed into a test tube and diluted with hexane 1:1 (v/v) and then vortexed thoroughly. Diluted oil was extracted using 3.0 mL of methanol:water (80:20, v/v) solvent. The sample was then vortexed and centrifuged at 3,000 rpm for 10 min and the supernatant was collected[17]. This step was repeated twice and all three extractions were combined. A 1 mL sample of extract was added to 0.5 mL of Folin-Ciocalteu reagent. After three minutes, 1.5 mL of 7% sodium carbonate solution was added, mixed and allowed to rest for two hours. The absorbance readings were taken at a wavelength of 765 nm on a 1100 Series spectrophotometer. The experiment was performed in triplicate. The quantification of TPC was conducted using a calibration curve prepared with a gallic acid standard ($R^2 = 0.9973$). The results were expressed as mg GAE kg^{-1} DW oil.

Determination of total antioxidant activity (TAA): The TAA of the *Passiflora* seed oils was determined against DPPH radicals according to the modified methods of Kalantzakis *et al.*[18] and Malacrida and Jorge[10]. The oil extraction was carried out by diluting 1 mL of the oil with 10 mL ethyl acetate. One millilitre (1 mL) of diluted oil was added to 4.0 mL of DPPH (1×10^{-4} M) and vortex thoroughly. After a 30 min incubation period, the absorbance was measured against the blank prepared without extract at a wavelength of 517 nm on a 1100 Series spectrophotometer. The concentration of the sample required to scavenge 50% DPPH (EC_{50}) was determined by linear regression for the concentration and EC_{50} (%). The experiment was performed in triplicate and the results were expressed as mg mL^{-1}.

Statistical analysis: The results were statistically analysed using SAS window programme 9.1 (SAS, Buckinghamshire, UK). Means, standard errors and ranges for the physicochemical characteristics and antioxidant properties were computed for triplicate determination. Means were compared using single-factor ANOVA. Post-hoc Tukey's test ($p<0.05$) was performed if the ANOVA result was significant. The EC_{50} values for TAA were calculated by linear regression analysis. The data obtained from the *Passiflora* species were compared with data of other seed oils and ordinated with principal component analysis (PCA) based on the Pearson method using XLSTAT software version 2013.5 (Addinsoft, New York, USA) for Windows to obtain the relationship between variables (physicochemical and fatty acids) and seed oil crops.

RESULTS AND DISCUSSION

Physicochemical properties of seed oils: The obtained physicochemical properties of the *Passiflora* seed oils are presented in Table 1. The crude *Passiflora* seed oils extracted with petroleum ether are liquid with colours ranging from golden-orange to yellow and are odourless at room temperature (28°C). The properties of *Passiflora* seed oils were comparable with various commercial oils, including coconut, soybean, argan, corn, olive, sunflower and palm oil, as shown based on ordination with PCA and illustrated as biplots in (Fig. 1). Each species showed specific physicochemical characteristics producing oil with different compositions and properties. The PCA indicates that the first two PCs for the oil properties accounted for 73.44% of the total variance. PC1 explained a higher percentage of total variance (40.44%) than PC2 (33.00%). Most of the physicochemical parameters examined were loaded heavily on the PC1 sites, including SG, AV, PV, NSM, RI and IV, while oil content (OC) and SV were connected to the PC2 sites (Fig. 1a).

The seed oils from *Passiflora* species and other commercial seeds were clustered into four main groups based on their content similarities. From the generated biplot (Fig. 1b), all three examined *Passiflora* seed oils extracted from *P. edulis* (Purple), *P. quadrangularis* and *P. maliformis* were clustered in the first group with *P. edulis* oil, studied by Malacrida and Jorge[10] and Liu *et al.*[11], together with sunflower,

Table 1: Physicochemical properties of *Passiflora* seed oils compared to those of other commercial seed oils

Variables	*P. edulis* (Purple)	*P. quadrangularis*	*P. maliformis*	*P. edulis* f. *flavicarpa*	*P. edulis* Tainung No. 1'	Coconut oil	Palm oil	Soybean oil	Argan oil	Corn oil	Olive oil	Sun flower
OC	29.65±0.41^{a} (28.70-30.05)	26.81±0.44^{ab} (26.15-27.61)	24.34±0.46^{b} (23.72-25.28)	23.40	30.39	42.00	54.18	21.00	43.00	6.63	40.70	36.14
SG	0.899±0.01b (0.897-0.900)	0.903±0.01^{ab} (0.902-0.904)	0.908±0.02^{a} (0.904-0.911)	0.917	na	0.92	0.87	0.92	0.91	0.92	0.91	0.92
RI	1.46±0.01^{ab} (1.45-1.47)	1.45±0.01^{b} (1.45-1.46)	1.47±0.01^{b} (1.47-1.48)	1.47	1.47	1.45	1.45	1.47	1.47	1.46	1.47	1.47
AV	2.64±0.06^{b} (2.52-2.63)	4.87±0.41^{a} (4.24-5.59)	2.47±0.03^{b} (2.42-2.54)	2.11	2.35	0.40	0.50	2.72	0.40	4.97	1.79	0.80
PV	1.43±0.12^{b} (1.21-1.54)	3.23±0.12^{a} (3.04-3.47)	2.14±0.11^{b} (1.95-2.08)	2.23	1.46	0.20	4.10	21.38	1.00	10.00	22.50	1.33
SV	194.67±0.33^{ns} (194-195.0)	194.00±0.33^{ns} (192.0-193.0)	192.67±0.58^{ns} (193.0-195.0)	176.00	190.70	258.80	186.00	199.63	195.00	211.37	189.30	193.90
NSM	0.93±0.03^{ns}	1.00±0.00^{ns}	0.93±0.03^{ns}	0.90	1.51	0.10	0.53	1.00	0.48	1.20	1.50	1.03
IV	129.33±0.88^{a} (128.0-131.0)	124.67±0.67^{b} (124.0-126.0)	131.00±0.58^{a} (130.0-132.0)	119.90	128.0	5.50	50.20	119.21	93.40	47.25	83.60	132.30
FFA	1.31±0.02^{b} (1.28-1.34)	2.43±0.20^{a} (2.11-2.84)	1.24±0.01^{b} (1.23-1.25)	1.06*	1.18	0.20	0.25	1.36	0.20*	2.50	0.90	0.37
Ref.	Present study	Present study	Present study	Malacrida and Jorge[10]	Liu *et al.*[11]	Kamariah *et al.*[20]	Kuntom *et al.*[21]	Abitogun *et al.*[22]	Taribak *et al.*[42]	Amos-Tautua and Onigbinde[19]	Tanilgan *et al.*[43]	Rosa *et al.*[23]

Different superscript letters in the same row indicate differences at $p<0.05$ (ANOVA, Tukey's test). Values are given as the Means±standard deviation and values in parentheses are the range. OC: Oil content (%), SG: Specific gravity, RI: Refractive index, AV: Acid value (mg KOH g^{-1}), PV: Peroxide value (meq kg^{-1}), SV: Saponification value (mg KOH g^{-1}), NSM: Non-saponification matter (%), IV-Iodine value (g I_2 100 g^{-1}), FFA-Free fatty acid as oleic (%), ns: no significant difference, *Estimation value: % FFA (as oleic acid) x 1.99 = acid value

Fig. 1(a-b): (a) Plot of physicochemical properties of *Passiflora* seed oils and other commercial edible seed oils
The percentage in parentheses represents the variation in each component. (b) Positions of PC score of 12 seed oils analysed according to PC1 and PC2

olive and soybean oil. This group includes oils with a high RI, IV, FFA, PV, SG and NSM. The RI is related to molecular weight, fatty acid chain length and degree of unsaturation[19]. The RI of *Passiflora* seed oil was 1.45-1.47 and similar to many other edible oils, i.e., palm oil and olive oil. The IV measures the level of unsaturation in oil. The greater the IV, the higher the unsaturation and susceptibility to oxidation. The present results showed that the *Passiflora* seed oils studied were

highly unsaturated, with IVs ranging from 124.67±0.67 g I_2 100 g^{-1} to 131.00±0.58 g I_2 100 g^{-1} (Table 1) and were prone to oxidation compared to coconut[20] and palm oils[21] with 5.50 g I_2 100 g^{-1} and 50.20 g I_2 100 g^{-1}, respectively. The IV for *Passiflora* seed oil was consistent with those of the conventional edible seed oils, i.e., soybean[22] and sunflower[23], which fall between 119.21-132.30 g I_2 100 g^{-1} (Table 1). Based on its IV, *Passiflora* seed oil could be classified as semi-siccative, indicating that it is potentially useful in the food and chemical processing industries[24]. Free fatty acids (FFAs) and PVs are valuable measures of oil quality[25]. The lower the FFA value, the better the quality of the oil for human consumption. The FFA percentage of *Passiflora* seed oil and other commercial edible oils fall between the allowable limits (1.0-3.0%), as reported by Paul *et al.*[26]. The PV gives an indication of the primary oxidation state of oil. The PV of *Passiflora* seed oil and other seed oils in this cluster, including sunflower, was within the range given by CODEX standard ≤10.0 meq kg^{-1}. The high quality of *Passiflora* seed oil can be verified by its PV, which is related to the development of hydrolytic and oxidative reactions[10]. The SG values of the *Passiflora* seed oils were very close: 0.899±0.01-0.908±0.02. The percent NSM of oil checks for the contamination of foreign materials. Among the studied species, oil extracted from *P. quadrangularis* possessed a relatively higher NSM (1.0%) compared to *P. edulis* (Purple) and *P. maliformis*, which was 0.93%. Similarly, the NSM for other edible oils in this group was ≤1.5%. The slightly higher content of NSM may be due to the ability of the solvent to extract other lipid-associated substances, i.e., sterols, fat-soluble vitamins and hydrocarbons[27].

The second group was composed of corn oil, which had the highest AV. The AV indicates the level of rancidity of oil. The AV of corn oil (4.97 mg KOH g^{-1}) was similar to that of *P. quadrangularis* (4.87±0.41 mg KOH g^{-1}), which was two times higher than the value obtained for other *Passiflora* seed oils (approximately 2.6 mg KOH g^{-1}). Among the oils analysed, the AVs for argan, coconut and palm oils were within the range (≤0.6 mg KOH g^{-1}) given by FAO, while other edible oils possessed AVs ≥2.0 mg KOH g^{-1} and within the allowable limits for edible oil. Coconut oil was the sole member in the third cluster with the highest SV. The SV is a measure of the free and esterified acids present in oil. The SV for most of the edible oil falls within the range of 180-200 mg KOH g^{-1}. Although the SV value of coconut oil was higher (258.80 mg KOH g^{-1}), the value was within the range of the allowable limit (248-265 mg KOH g^{-1}) for coconut oil by FAO. Comparatively, the SV of *Passiflora* seed oil ranged from 192.67±0.58 to 194.67±0.33 mg KOH g^{-1}, which was in agreement with that reported for *P. edulis* f. *flavicarpa* (190.7 mg KOH g^{-1}) by Malacrida and Jorge[10]. These values are higher than those obtained by Liu *et al.*[11] for 'Tainung No. 1' passion fruit. The saponification value (SV) obtained for other edible oils, i.e., sunflower (193.90 mg KOH g^{-1}) and olive oils (189.30 mg KOH g^{-1}), were also within the allowable level by WHO (188-194 mg KOH g^{-1}). The fourth group comprised argan and palm oils with higher oil contents, 430.0 and 541.8 g kg^{-1}, respectively. The oil extracted from *Passiflora* seeds was two times less than the yield from palm oil kernel. The amount of oil extracted from *Passiflora* seeds using Soxtec solvent extraction ranged from 243.40±0.46 g kg^{-1} in *P. maliformis* to 296.50±0.41 g kg^{-1} in *P. edulis* (Purple), which falls within the range 234.0-303.9 g kg^{-1} in other *P. edulis* species reported by Malacrida and Jorge[10] and Liu *et al.*[11] and the present result was slightly lower than that of sunflower seeds (361.4 g kg^{-1}). Among the seeds evaluated, the oil yield from corn was low (66.3 g kg^{-1}), followed by soybean (210 g kg^{-1}). Different species exhibited varying contents of oil and oil properties. As reported by Kodad and Socias I Company[28], the composition of *Passiflora* seed oil and its characteristics were dependent on the genotypes of cultivars and were also attributed to climate, geographical factors and agronomic conditions and agriculture practices.

Fatty acid composition of the seed oil: The fatty acid compositions of the examined *Passiflora* species are presented in Table 2. For physicochemical properties, the fatty acid composition was also compared with other commercial edible oils that were ordinated with PCA and illustrated as a biplot in Fig. 2. For the fatty acid composition, the first two principal components explained 71.41% of the total variance, with PC1 and PC2 representing 44.70 and 26.71% of the total variance, respectively. Most of the methyl ester composition examined was loaded heavily on the PC1 sites, including oleic acid (C18:1), araquidic acid (C20:0), behenic acid (C22:0), stearic acid (C18:0), linolenic acid (C18:3), palmitoleic acid (C16:1), linoleic acid (C18:2), total UFA, MUFA and PUFA, while the total SFA and its major contributors, lauric acid (C12:0), miristic acid (C14:0) and palmitic acid (C16:0), were connected to the PC2 sites (Fig. 2a).

The biplot generated four main groups (Fig. 2b) based on their fatty acid composition similarities. The first group consisted of the studied *Passiflora* seed oils from *P. edulis* (Purple), *P. quadrangularis* and *P. maliformis*, two previously studied *Passiflora* seed oils (*P. edulis* f. *flavicarpa* and 'Tainung No. 1' passion fruit), corn, soybean and sunflower oil. They clustered together due to the UFA content, which was much higher than the total SFA content comparatively.

Table 2: Fatty acid composition (%) of *Passiflora* seed oils compared to that of other commercial seed oils

Variables	*P. edulis* (Purple)	*P. quadrangularis*	*P. maliformis*	*P. edulis* f. *flavicarpa*	*P. edulis* Tainung No. 1'	Coconut oil	Palm oil	Soybean oil	Argan oil	Corn oil	Olive oil	Sunflower oil
C12:0	nd	0.20	nd	nd	nd	47.1	0.1	nd	nd	0.1	0.1	nd
C14:0	0.12	0.38	0.14	0.03	tr	17.7	1.0	0.1	0.3	nd	0.1	0.1
C16:0	10.50	13.14	9.67	8.57	9.73	7.9	43.7	10.3	11.3	12.4	10.1	6.2
C16:1	0.23	1.38	0.23	0.23	0.11	nd	0.1	5.2	nd	nd	0.7	0.1
C18:0	3.13	3.03	2.40	1.66	2.58	2.6	4.4	3.8	6.7	11.4	3.0	4.3
C18:1	14.47	17.30	14.10	16.25	13.83	4.5	31.9	22.8	45.2	37.0	71.9	20.2
C18:2	70.42	63.20	68.41	72.69	73.14	0.8	10.3	51.0	32.4	47.2	7.5	63.2
C18:3	0.57	0.96	0.43	0.26	0.41	nd	nd	6.8	0.6	1.3	nd	nd
C20:0	0.23	0.14	0.12	nd	0.10	nd	0.3	nd	nd	0.3	0.4	0.3
C22:0	0.12	0.22	0.13	nd	0.10	nd	nd	nd	nd	0.2	0.1	0.8
UFA	85.69	82.84	83.17	89.43	87.59	5.3	42.3	85.8	78.2	85.5	80.1	83.5
MUFA	14.70	18.68	14.33	16.48	14.04	4.5	32.0	28.0	45.2	37.0	72.6	20.3
PUFA	70.99	64.16	68.84	72.95	73.55	0.8	10.3	57.8	33.0	48.8	7.5	63.2
SFA	14.10	17.11	12.46	10.26	12.41	75.3	49.5	14.2	18.3	24.4	13.8	11.7
Ref.	Present study	Present study	Present study	Malacrida and Jorge[10]	Liu *et al.*[11]	Kamariah *et al.*[20]	Kuntom *et al.*[21]	Oladiji *et al.*[33]	Taribak *et al.*[42]	Daugan *et al.*[44]	McKevith[40]	McKevith[40]

C12:0-Lauric acid, C14:0-Miristic acid, C16:0-Palmitic acid, C16:1-Palmitoleic acid, C18:0-Stearic acid, C18:1-Oleic acid, C18:2-Linoleic acid, C18:3-Linolenic acid, C20:0-Araquidic acid, C22:0-Behenic acid, UFA: Unsaturated fatty acids, MUFA: Monounsaturated fatty acids, PUFA: Polyunsaturated fatty acids, SFA: Saturated fatty acids, tr-trace, nd: not detected

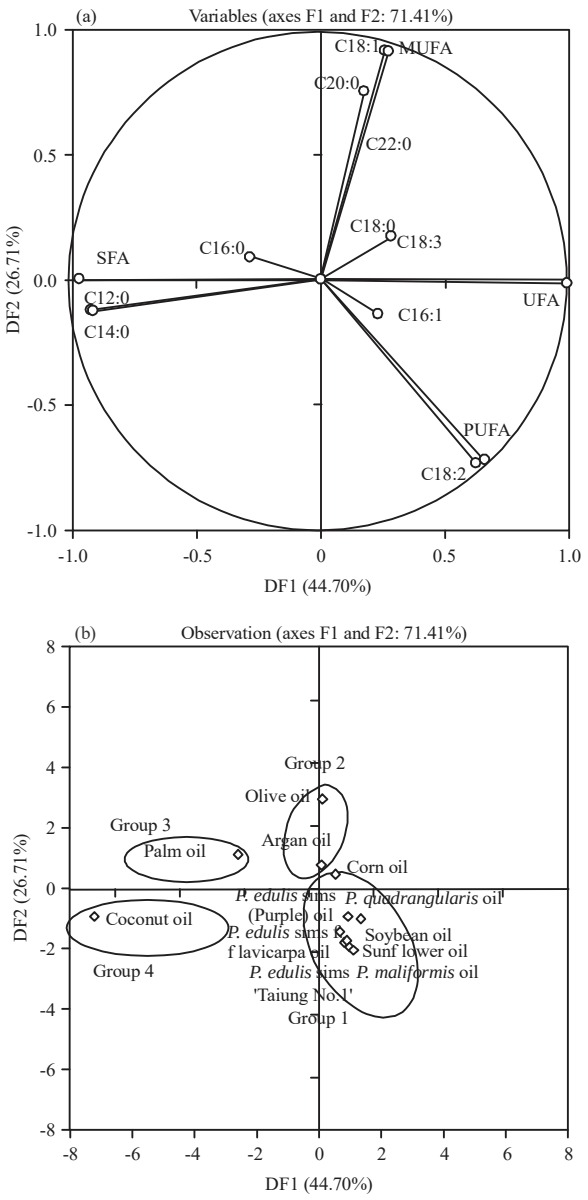

Fig. 2(a-b): (a) Plot of fatty acid compositions of *Passiflora* seed oil and other commercial edible seed oils
The percentage in parentheses represents the variation in each component. (b) Positions of PC score of 12 seed oils analysed according to PC1 and PC2

The *Passiflora* seed oil contains a total UFA content of 82.84-85.69%, which is predominantly composed of PUFAs (64.16-70.99%), linoleic acid (63.20-70.42%) and a low level of linolenic acid (0.43-0.96%) rather than the MUFAs (14.33-18.68%). The majority of SFAs were palmitic acid (9.67-13.14%) and stearic acid (2.40-3.13%). A similar trend was also observed in other commercial edible oils in this cluster, including sunflower, corn and soybean oils, with the

most prevalent UFA being linoleic acid, followed by oleic acid. Moreover, the total PUFA content in the seed oil of *Passiflora* species was found at higher levels than those in the common edible oils, such as soybean and nuts oil. The results obtained for the UFAs were in agreement with Wardlaw[29], demonstrating that plant oil content was mostly UFAs that ranged from 73-94% of the total lipid content. Liu *et al.*[11] suggested that the oil must be stored unexposed to air and at a lower temperature due to its high content of UFAs. From the present findings, lauric acid is not detectable in *P. edulis* (Purple) and *P. maliformis* and *P. quadrangularis* possessed a low detectable amount at 0.2%. This study also revealed variation between the fatty acid composition of oil extracted from *P. edulis* (Purple), *P. quadrangularis* and *P. maliformis* and indicated slight differences from that reported for *P. edulis* species from different regions. This was in agreement with the findings of other authors concerning the fatty acid composition in other plants, i.e., 21 grape varieties (*Vitis* spp.) and the fatty acid profile depends on the genotype, cultivation conditions and cultivar aptitude[30].

The second group comprised olive and argan oil. This group includes oils with a higher UFA content as in the previous group and mainly comprised the MUFA of oleic acid. These edible oils had a higher MUFA content that ranged from 45.2- 2.6% with nearly 99% (45.2-71.9%) oleic acid. Among the edible oils, olive oil possessed higher oleic acid (76%) than other fatty acid components[31]. Palm oil, which is an important edible oil, is the only member in the third cluster that possesses a 1:1 ratio of SFAs and UFAs at 49.5 and 42.3%, respectively (Table 2). The majority of the SFA content of palm oil was palmitic acid (43.7%) >stearic (4.4%) >meristic (1.0%) and lower content of araquidic acid (0.3%) and lauric (0.1%), while UFAs comprised oleic (31.9%) and linolenic acid (10.3%) in palm oil[21]. The last group with coconut oil had higher values of SFAs (75.3%) compared to the lower content of UFAs (5.3%). The lauric and meristic acids were the dominant fatty acids in this oil at 47.1 and 17.7%, respectively[20].

The above comparison revealed that *Passiflora* seed oil possessed characteristics similar to sunflower and soybean vegetable oils based on physicochemical properties and fatty acid composition. The findings indicated the usability of the seeds in a human diet and in the production of other commercial products. According to a classification by Dubois *et al.*[32], passion fruit seed oil belonged to the polyunsaturated oil class, containing greater linoleic and oleic acid similar to most of the commercial edible oils, i.e., sunflower, soybean and corn oil. In addition, criteria to produce a good quality and digestible edible oil are determined by the amount of UFAs. The fatty acid profile of *Passiflora* seed oil, having a higher UFA content and a low percentage of SFAs, is considered ideal for edible oil, indicating that *Passiflora* seed oil can be employed in cooking, potentially used as salad oil and used in the preparation of margarine and mayonnaise. Comparing the total SFA and UFA ratio to those reported by Oladiji *et al.*[33] *P. edulis* (Purple) seed oil (1/6.08) is similar to soybean oil (1/6.04). The primary concerns with fatty acid consumption relate to two chronic diseases, coronary heart disease (CHD) and cancer. The consumption of SFAs with 12, 14 and 16 carbon atoms may increase total blood cholesterol and be harmful to the cardiovascular system[34]. Dietary intake of certain UFAs, in particular linoleic acid, is important in human food because of its prevention of certain cardiovascular diseases[35]. Walia *et al.*[36] stated that apple seed oils possess a good UFA composition for the forti cation or development of nutritional supplements, especially in the management of cardiometabolic disorders. Many studies have shown that diets enriched in PUFAs can significantly lower blood pressure. *Passiflora* seed oil has properties similar in Fig. 2 to those of corn oil and the consumption of corn oil can lower blood pressure. In addition to being used in the food industry, *Passiflora* seed oil due to its high PUFA composition is also potentially useful for skin and as hair conditioners, as moisturizing agents and in cosmetic formulations. *Passiflora* seed oil also possesses a high number of low molecular weight fatty acids and can thus be used in the soap industry. A high level of UFAs showed that the oil from *Passiflora* seeds is classified as a non-drying oil, which is potentially useful in paint, detergent and cosmetic industries[10].

Total phenolic content (TPC) and total antioxidant activity (TAA): Experiments have been carried out and established the potential effect of plant-based natural antioxidants on the oxidative stability of oil for both edible and industrial uses[37]. Recently, the presence of phenolic contents in seed oils (berries: blackberry, blueberry, strawberry and cranberry) has been discovered, offering interesting nutritional and economical possibilities[38]. With regard to seed oil of *Passiflora* species, the phenolic content varied between species and among the extracted seed oil tested, *P. edulis* (Purple) had the maximum TPC (570.74±0.78 mg kg^{-1}), followed by *P. maliformis* (537.83±1.40 mg kg^{-1}) and oil extracted from *P. quadrangularis* seeds had lower phenolic content (516.38±2.73 mg kg^{-1}) (Table 3). The TPC of oil extracted from *P. edulis* f. *flavicarpa* as reported by Malacrida and Jorge[10] was two times higher (1314.13±14.43 mg kg^{-1}) than the results obtained in this study. With respect to phenolic

Table 3: Total phenolic content (mg kg^{-1}) and antioxidant activity (mg mL^{-1}) of *Passiflora* seed oil

Variables	*P. edulis* (Purple)	*P. quadrangularis*	*P. maliformis*
Total phenolic content (TPC)	570.74±0.78[a]	516.38±2.73[b]	537.83±1.40[ab]
	(561.00-580.94)	(498.20-532.80)	(527.17-551.19)
Total antioxidant activity (TAA)	33.63±1.46[c]	49.95±0.93[a]	46.03±1.63[b]
	(31.22-36.29)	(48.30-51.53)	(43.58-49.12)

Different superscript letters within the same row indicate significant differences (ANOVA, Tukey's test, $p<0.05$) among the means of each variable of the *Passiflora* species seed oil

compounds, the concentration in the *Passiflora* seed oil was comparable to other oil crops, such as coconut kernel (56.2±4.6 mg kg^{-1}), palm (76.7±2.8 mg kg^{-1}) and rice bran (309.3±5.2 mg kg^{-1})[39], while sunflower seed oil possessed a higher phenolic content at 1601 mg kg^{-1} [40].

Antioxidant activity of the analysed *Passiflora* seed oil measured by DPPH assay is shown in Table 3. The present results indicated that the *Passiflora* seed oil possessed free radical scavenging activity. A lower EC_{50} value indicates a greater antioxidant activity for a given oil. The TAA ranged from 33.63±1.46-49.95±0.93 mg mL^{-1} for oil extracted from various *Passiflora* seeds. From the TPC results, the strongest TAA was observed in the oil recovered from *P. edulis* (Purple) seeds (33.63±1.46 mg mL^{-1}), followed by *P. maliformis* (46.03±1.63 mg mL^{-1}) and the lowest antioxidant activity was observed in *P. quadrangularis* (49.95±0.93 mg mL^{-1}) oil. The present TAA values were lower than those from the previously investigated seed oil from *P. edulis* f. *flavicarpa* (10.62 g g^{-1})[10]. The lower antioxidant activity obtained in the present study may be attributed to the Soxtec extraction method, which caused the loss of natural antioxidant compounds during heating, as reported by Sultana *et al.*[41]. In recent years, researchers have shown increasing interest in vegetable oil due to its rich source of natural oxidants such as tocopherols, carotenoids, sterols and phenolic compounds. Studies have indicated that these phytochemicals have high free-radical scavenging activities, which helps reduce the risk of chronic diseases, such as cardiovascular disease, cancer and age-related neuronal degeneration[34]. Findings by Malacrida and Jorge[10] showed that *P. edulis* f. *flavicarpa* possessed good δ- and g-tocopherol, which are more active antioxidants than α- and β-tocopherol. This suggests that *Passiflora* seed oil could provide health benefits if used in food by fighting free radicals *in vivo*.

CONCLUSION

Based on the present study, the passion fruit, in addition to being processed as juice, can also be explored for oil production. The extracted oil possessed essential fatty acids, mainly unsaturated fatty acids (linoleic acid and oleic acid) and saturated fatty acids (palmitic acid), an indicator that the oil is categorized as premium edible oil. *Passiflora* seeds used in this study are generally underutilized by-products and could be used as raw materials in producing edible oil and other products for industrial applications. Seed oil also contains constituents with significant phenolic and antioxidant properties for pharmaceutical and nutraceutical uses. More studies are necessary to evaluate the potential extracted oil and its components.

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