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ORIGINAL ARTICLE

Expeller pressing of passion fruit seed oil: Pressing efficiency and quality of oil

Prensagem de semente de maracujá: Eficiência da prensagem e qualidade do óleo

Rosemar Antoniassi[1]*, Allan Eduardo Wilhelm[1], Sandro Luis Rosa Reis[2], Suelen Alvarenga Regis[3], Adelia Ferreira Faria-Machado[1], Humberto Ribeiro Bizzo[4], Sérgio Agostinho Cenci[5]

[1]Embrapa Agroindústria de Alimentos, Laboratório de Óleos Graxos, Rio de Janeiro/ RJ - Brasil
[2]Grupo Extrair - Gestão de Projetos e Negócios, Bom Jesus de Itabapoana/RJ - Brasil
[3]Universidade Estadual do Norte Fluminense Darcy Ribeiro (UENF), Laboratório de Tecnologia de Alimentos, Campos dos Goytacazes/RJ - Brasil
[4]Embrapa Agroindústria de Alimentos, Laboratório de Cromatografia Gasosa, Rio de Janeiro/RJ – Brasil
[5]Embrapa Agroindústria de Alimentos, Planta Piloto de Pós-colheita, Rio de Janeiro/RJ - Brasil

***Corresponding Author:** Rosemar Antoniassi, Embrapa Agroindústria de Alimentos, Laboratório de Óleos Graxos, Av. das Américas, 29501, CEP: 23020-470, Rio de Janeiro/RJ - Brasil, e-mail: rosemar.antoniassi@embrapa.br

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Abstract

The passion fruit juice production generates around 70% of by-products comprising rind, seeds and arils that are commonly discarded. The seeds consist of 4% of fruit weight with the potential to produce around 2,500 ton/year of high added-value oil in Brazil. In this work, passion fruit seeds from different juice manufacturers and the effect of the seed moisture were evaluated towards oil quality and extraction efficiency, using a continuous expeller press of 100 kg/h capacity. The seeds were washed and dried before pressing. The main fatty acids detected were linoleic (67% to 68%), oleic (16% to 17.4%) and palmitic (11%). The oil quality and oil recovery depended on the seed oil content, *i.e.*, the seed moisture before pressing and the different provenances of the seeds. Significant differences were observed for oxidative stability, acidity and conjugated dienes ($p < 0.05$) for oils from different fruit juice manufacturers. Among them, only one met the requirements of Brazilian regulation regarding oil acidity (less than 2%), thus indicating the need for an effective waste treatment process after juice extraction. Regarding the seed moisture, the highest Oil Stability Index (OSI) (7.4 h) and lowest free fatty acid content (0.63%) were obtained for the oil from the lowest seed moisture content. The oil recovery varied from 78% to 89% and the cake oil content was lower than 8% showing the elements of the feasibility of the process to obtain good quality oil.

Keywords: *Passiflora edulis*; Oil recovery; Fatty acids; Oil stability; Seed moisture; By-product.

Resumo

A produção de suco de maracujá gera cerca de 70% de coprodutos compostos de casca, sementes e arilos, que costumam ser descartados. As sementes consistem em 4% do peso do fruto, com potencial para produzir em torno de 2.500 ton/ano de óleo de alto valor agregado, no Brasil. Neste trabalho, sementes de maracujá de diferentes fabricantes de suco e o efeito da umidade das sementes foram avaliados quanto a qualidade do óleo e eficiência de extração, utilizando uma prensa contínua (expeller) de 100 kg/h de capacidade, sendo que as sementes foram lavadas e secas antes da prensagem. Os principais ácidos graxos detectados foram linoleico (67% a 68%), oleico (16% a 17,4%) e palmítico (11%). A qualidade do óleo e o rendimento do processo dependeram do teor de óleo da semente, da umidade da semente antes da prensagem e das diferentes procedências das sementes. Diferenças significativas foram observadas para estabilidade oxidativa, acidez e dienos conjugados ($p<0,05$) para óleos obtidos de sementes de diferentes fabricantes de sucos de frutas. Dentre estes, apenas um atendeu aos requisitos da regulamentação brasileira quanto à acidez do óleo (menos de 2%), indicando a necessidade de um processo eficaz de tratamento de resíduos após a obtenção do suco. Em relação à umidade da semente, o maior índice de estabilidade do óleo- OSI (7,4 h) e o menor teor de ácidos graxos livres (0,63%) foram obtidos para o óleo a partir da semente de menor umidade. A recuperação de óleo variou de 78% a 89% e o teor de óleo da torta foi inferior a 8%, mostrando a viabilidade do processo para obtenção de óleo de boa qualidade.

Palavras-chave: *Passiflora edulis*; Rendimento de óleo; Ácidos graxos; Estabilidade oxidativa; Umidade da semente; Coproduto.

Highlights

- The passion fruit seed is a cheap and available oil source of good quality.
- The oil quality depends on the oil extraction conditions and seed provenance.
- There are no reports about the effect of seed moisture on the pressing efficiency of passion seed.
- The high oil recovery and the low cake oil content showed the feasibility of pressing extraction.

1 Introduction

The production of juices by the food industry generates thousands of tons of waste that are disposed of without any treatment and may result in pollution of the environment. In recent years, emerging technologies together with the increasing concern about sustainability and environmental conservation have motivated many studies that aimed to investigate possible applications for these by-products (Fierascu et al., 2020). Several fruit wastes, as a cheap source of valuable components, have been investigated for high-added value constituents (Espírito-Santo et al., 2013; Kawakami et al., 2021; Matsui et al., 2010; Pereira et al., 2019).

Brazil is the largest producer of passion fruit, followed by Colombia and Indonesia, and accounted for around 65% of the world production of passion fruit, estimated to be circa 1,468 thousand tons (Altendorf, 2018). The total production of passion fruit in Brazil reached 690,364 tons in 2020 (Instituto Brasileiro de Geografia e Estatistica, 2020). Brazil holds for a long time a well-established passion fruit industry with large-scale juice extraction plants and around 50% of Brazilian passion fruit production is used for industrial processing (Cavichioli et al., 2018). After juice processing, circa 65-70% of fresh fruit weight is discarded, comprising rind, seeds and arils (Regis et al., 2017).

The yield and characteristics of these potential coproducts from Brazilian passion fruit have been investigated in order to evaluate the possible applications (Oliveira et al., 2011; Talma et al., 2019; Wilhelm et al., 2014). The seeds account for 4% of the fruit weight (Regis et al., 2015; Regis et al., 2017), and contain 25% to 30% of oil (Wilhelm et al. 2014), rendering a potential to produce around 2,500 ton of oil/year in Brazil. The use of passion fruit seed oil by pharmaceutical and cosmetics segments, as well as the properties of its bioactive components and their potential beneficial role for human health were extensively reviewed by Lucarini et al. (2019) and Corrêa et al. (2016). This oil was also evaluated as biofuel by Iha et al. (2018). In Brazil, there is a demand for dried passion fruit seeds that are marketed as a decorative element for desserts as well as for passion seed oil and for recovery of phenolic compounds. The oil market is focused on the cosmetic industry and therapeutic applications for skin treatment (Cesar et al., 2022).

Concerning the oil extraction process for passion fruit seed, there are several studies reporting the use of Supercritical Carbon Dioxide (SCD) assisted by ultrasound (Barrales et al., 2015), solvent extraction with hexane, acetone, ethanol and isopropanol (Malacrida & Jorge 2012; Oliveira et al., 2013, 2014), Surfactant-Assisted Aqueous Extraction (SAAE) (Surlehan et al., 2019), Ultrasound-Assisted Extraction (UAE) with ethanol and subcritical propane extraction (Pereira et al., 2019) and UAE by Massa et al. (2021). However, these techniques present limiting factors mainly related to the high costs involved and although lab bench essays provide good yield and quality results for passion fruit seed oil, scale-up the process to small and medium-sized industries may not be economically feasible. Solvent extraction is economically justified for large scale industrial plants and crop production. Furthermore, the use of fossil fuels is undesirable. Industrial scale production of passion fruit seed oil is usually achieved by pressing, which renders a cheaper and useful seed oil. Wilhelm et al. (2014) reported passion fruit seed continuous pressing conditions and oil quality characteristics using an expeller press up to 5 kg/h capacity.

Continuous pressing is currently the most commonly used in the processing of oleaginous materials. This method can be used from farm scale (3 to 100 kg/h) to industrial scale (up to 1800 ton/day). The efficiency of this process depends on the screw rotation speed, back pressure, temperature and material characteristics (water content and pre-treatment) (Savoire et al., 2013; Martínez et al., 2017; Rabadán et al., 2018). Furthermore, oil quality is critical to commercial feasibility (Evangelista, 2009; Martínez et al., 2013; Singh et al., 2002). Additionally, the passion seeds from juice extraction are agglomerated with arils and juice residue which promotes fermentation (Regis et al., 2015), and in order to produce clean seeds to allow drying, the washing step is required.

The Brazilian production of passion fruit is high and there is potential for the production of oil from the (discarded) seeds. Small-scale pressing is consistent with the amount of seed available, however, results from pressing of passion fruit seed are sparse. Pressing conditions may affect both oil recovery and quality. This study was carried out to evaluate the yield, recovery and quality of the oil obtained by pressing as influenced by different fruit juice manufacturers and the moisture content of the passion fruit seeds.

2 Material and methods

2.1 Material

Passion fruit seeds (*Passiflora edulis* Sims) were collected in different passion fruit juice manufacturers (PFJ) in Rio de Janeiro and Espírito Santo States, Brazil.

2.2 Processing

The processing was carried out in the facilities of Extrair Óleos Naturais (Bom Jesus de Itabapoana, Rio de Janeiro State, Brazil). The seeds were immediately washed after arrival with tap water in order to remove fruit juice residues and arils in the equipment of stainless steel specially developed for this operation which is in the step of writing a patent application form, as it was shown in Figure 1. The drying was carried out in a rotary drum dryer of 1600 kg capacity with hot air at 60 °C. The different moisture content of the seeds was obtained at different times of drying. The oil extraction was performed in a continuous stainless steel screw press (expeller) of 100 kg/hour maximum capacity (Ecirtec©, Bauru, São Paulo State, Brazil). The seeds without heat pre-treatment were used and the feed rate (20 to 30 kg/h) and rotation speed (50 rpm) and restriction die (5 mm) were adjusted. After 30 minutes of operation, the steady state was reached and oil and the press cake (partially defatted cake) were collected to achieve up to 1-2 hours of operation. The press cake was grounded and homogenized and the oil was obtained after the removal of the solid particles by gravity settling.

The oil yield and oil recovery in Dry Weight (DW) were calculated according to Equations 1 and 2, respectively:

$$\text{Oil yield (\%)DW} = \frac{\begin{pmatrix} seed\ weight(DW) \times \\ seed\ oil\ content(\%)\ DW \end{pmatrix} - \begin{pmatrix} cake\ weight(DW) \times \\ cake\ oil\ content(\%)\ DW \end{pmatrix}}{seed\ weight(DW)} \quad (1)$$

$$\text{Oil recovery(\%)DW} = \frac{oil\ yield(\%)\ DW)x100}{seed\ oil\ content(\%)\ DW} \quad (2)$$

2.3 Seed, cake and oil analysis

In order to quantify the seed and cake oil content after oil pressing, passion fruit seeds and cake were grounded and oil extraction was performed with petroleum ether (30 °C to 60 °C) in a Soxhlet apparatus for 16 h. The moisture of seeds and cake was performed in an oven-drying/gravimetric method at 105 °C (American Oil Chemist's Society, 2009). During processing the moisture was measured in an Infrared moisture analyzer (Kern model DLB, DE).

The acidity and peroxide value of oil were measured according to American Oil Chemists' Society (AOCS) Official Methods (American Oil Chemist's Society 2009). Oil Stability Index (OSI) measurements were performed in a Rancimat 679 (Metrohm, Herisau, CH) at 110 °C, using an airflow of 10 L/h and 5 g of sample, according to AOCS (American Oil Chemist's Society, 2009). Refraction index was carried out in an Abbe refractometer (Bausch and Lomb, USA) at 40 °C and specific gravity (20 °C) was measured in a DWA 46 Density Meter (Anton-Paar, DE).

Methyl esters of fatty acids were prepared according to Hartman & Lago (1973). Gas Chromatography (GC) was performed in an Agilent 6890 GC (Wilmington, USA) fitted with a cyanopropyl siloxane capillary column (60 m x 0.32 mm x 0.25 µm), with the following temperature program: initial column temperature was set to 100 °C and held for 3 min; then, it was increased to 150 °C at a rate of 50 °C/min, further increased to 180 °C at 1 °C/min, and finally increased to 200 °C at 25 °C/min, and kept for 10 minutes at this temperature. Hydrogen was used as carrier gas at a flow rate of 2.5 mL/min (measured at 40 °C). One µL of a 2% dichloromethane solution of the sample was injected, using an injector operating at 250 °C in split mode (1:50). The Flame Ionization Detector (FID) was held at 280 °C. The results were expressed as weight percentage (area normalization). The identification of Fatty Acid Methyl Ester (FAME) was based on a comparison of retention times with those of the NU CHEK 62, 79 and 87 standards (Elysian, MN, USA).

The Iodine value and Saponification value were calculated from the average of fatty acid composition, according to the official methods Cd 1c 85 and Cd 3a 94, respectively (American Oil Chemist's Society, 2009).

2.4 Statistical analysis

One-way Analysis of Variance (ANOVA) and Tukey's test were carried out to determinate differences among samples and for all tests the significant level was α of 5%. All analyses were performed by using Statgraphics (Manugistics, 1993).

3 Results and discussion

3.1 Passion fruit seed from different fruit juice manufacturers

Regarding the fatty acid composition, significant differences ($p < 0.05$) among seed sources were observed for stearic (C18:0), oleic (C18:1) and linoleic (C18:2) (Table 1). The main fatty acids of passion fruit seed oil were linoleic (67.0% to 69.0%), oleic (16.0% to 17.5%), palmitic (C16:0) (11.0% to 11.3%) and stearic (2.9% to 3.2%). Linolenic acid (C18:3) was quantified up to 0.4%, whereas myristic (C14:0), palmitoleic (C16:1), margaric (C17:0), C18:1 *trans*, arachidic (C20:0), gadoleic (C20:1), behenic (C22:0) and lignoceric (C24:0) were detected up to 0.2% (Table 1). Linoleic acid (C18:2 n-6) and linolenic acid (C18:3 n-3) are essential fatty acids and required for good health (Matsungo & Siziba, 2020). The passion fruit seed oil may contribute to daily intake of linoleic acid because the level of linolenic acid was low.

These ranges were similar to the fatty acid composition of Brazilian *P. edulis* seed oils reported by Lopes et al. (2010), Regis et al. (2015), Wilhelm et al. (2014) and Santana et al. (2015) and in agreement with those reported by Nyanzi et al. (2005) and Chumjai & Tippayawong (2012) of oils from Uganda and Thailand, respectively. However, Malacrida & Jorge (2012) and Liu et al. (2008) showed 73% of linoleic acid (C18:2) for single samples from Brazil and China, respectively. Meletti (2011) estimated that the species *P. edulis* accounts to more than 95% of commercial production in Brazil due to the quality of its fruits, productivity and juice yield.

Furthermore, the refraction index, iodine and saponification values, which depend on the fatty acid composition, showed significant difference for oils from different provenances ($p < 0.05$). These ranges observed were from 1.4607 to 1.4677 (40 °C), 132.4 to 134.5 g I2/100g and 193.2 to 193.4 mg KOH/g, respectively (Table 2). The relative density (20 °C) varied from 0.917 to 0.919 (Table 2), in the range of edible oils reported by Codex Alimentarius (Food and Agriculture Organization, 1999).

The oil content of passion fruit seeds from different juice manufacturers (PFJ) varied from 27.6 to 32.4% (w/w dry basis). Significant differences ($p < 0.05$) were observed, and the seed oil content of PFJ 1 and PFJ 2 was higher than PFJ 3 and PFJ 4 (Table 2, Figure 2). These results were similar to the oil content of passion fruit seed from Brazil reported by Lopes et al. (2010), Malacrida & Jorge (2012), Regis et al. (2015) and Wilhelm et al. (2014), but higher than the results of *P. edulis* seeds from Africa (Nyanzi et al., 2005) and China (Liu et al., 2008).

The expeller pressing of seeds was possible after the washing process of seeds which successfully removed arils and juice residue and allowed the seed drying (Figure 1). The expeller pressing of seeds with higher seed oil content (PFJ1 and PFJ2) presented higher oil yield (28%) and oil recovery (87% to 89%) than PFJ3 and PFJ4 ($p < 0.05$). Although, no significant differences were recorded ($p < 0.05$) in the residual oil content of the cake (4.9% to 6.7% DW), but showing the trend of reducing cake oil content with increment of seed oil content (Figure 2). Chumjai & Tippayawong (2012) reported an oil yield of 20% for screw pressing of passion fruit seed, but the seed oil content and process conditions were not reported. On the other hand, Wilhelm et al. (2014) working with a lab scale expeller pressing system, reported an oil yield of around 24% for seeds with 30.6% of oil content (dry basis), and oil recovery and cake oil content ranging from 86 to 88% and 5.2 to 5.6%, respectively, with different screw press feed rates.

The oil acidity varied from 1.1 to 13.6% (expressed as oleic acid) and it was attributed to fruit moisture, presence of broken seeds from the juice extraction process and conditions of storage the waste after fruit processing (Table 2). Typically small- and medium-scale industrial operations of passion fruit in Brazil operate with daily production ranging from 10 to 100 ton. The pulp waste (seeds, arils and juice residue) has high moisture content and prompt fermentation is observed (Regis et al., 2015). Oil acidity is a product of lipase activity that hydrolyzes triglycerides into free fatty acids, partial glycerides and glycerol which is favored by the moisture of seeds or oily fruits. The oil acidity up to 13.7% addresses the need for treatment of waste and drying of seeds in order to produce high quality oil. After juice extraction, the seeds should be cleaned to enable the separation of arils and juice residue which was performed in this work by water washing followed by drying (Figure 1). This cleaning was performed in specially developed equipment. As far as we know, there are no reports of such a process of cleaning of fruit seeds before oil pressing. Nevertheless, the difference observed for acidity pointed out the differences in seed storage time before washing and drying. For commercial purposes, the seed treatment or cleaning followed by drying should be performed as soon as possible after juice extraction. Only one passion fruit seed oil obtained met the requirements of Brazilian regulation regarding the oil acidity (less than 2%) for crude oils obtained by pressing (Brasil, 2021). The free fatty acid content for passion fruit seed oil observed by Wilhelm et al. (2014), Chumjai & Tippayawong (2012), Kobori & Jorge (2005) and Malacrida & Jorge (2012) ranged from 0.7% to 7.35% but Iha et al. (2018) reported around 50% of free fatty acid content.

The outlet oil temperature ranged from 28 °C to 56 °C, due to the compression and friction, once the whole seed was added to the expeller at room temperature (Table 2). The equipment used did not allow temperature control as heating or cooling and the obtained oils from the expeller might not be called "cold pressed oils". The temperature, however, should be controlled to avoid oil oxidation during pressing (Rabadán et al., 2018). Oxidation of edible oils is influenced by light, heat, fatty acids, and minor compounds such as metals, pigments, phospholipids, free fatty acids, and antioxidants (Laguerre et al, 2020). Despite the low initial level of oxidation measured as peroxide value, conjugated dienes varied from 0.16% to 0.25% ($p < 0.05$), and the highest values were also related to the oils with higher acidity observed for PFJ 3 and PFJ 1. Wilhelm et al. (2014) reported conjugated dienes for passion fruit seed oil up to 0.15%. Conjugated dienes and hydroperoxides are primary products of the oxidation of polyunsaturated lipids (Laguerre et al., 2020). The presence of conjugated dienes and *trans* fatty acids (Table 1) pointed out the alteration of the fatty acid profile due to the temperature rising during pressing. The *trans* fatty acids are mainly found in hydrogenated and deodorized oils and after frying as well as a consequence of temperature rising. The increase in the temperature during pressing can cause a reduction in the oil quality (Rabadán et al., 2018).

The OSI varied from 6.5 to 8.8 hours ($p < 0.05$) (Rancimat at 110 °C and 10 L/h), similar to the data obtained by Wilhelm et al. (2014) for pressed oils and by Regis et al. (2015) and Malacrida & Jorge (2012) for solvent extracted oils, which ranged from 4.5 to 7.9 hours.

The seeds from PFJ 4, that presented the lowest acidity and consistent with Brazilian regulation were chosen for further expeller pressing assays with different seed moisture levels.

Table 1. Fatty acid composition (g fatty acid/100 g total fatty acids)* of seed oils from different Passion Fruit Juice (PFJ) manufacturers.

Fatty acid	PFJ 1	PFJ 2	PFJ 3	PFJ 4
C14:0	0.09 ± 0.001	0.07 ± 0.001	0.08 ± 0.001	0.08 ± 0.001
C16:0	11.18 ± 0.123[a]	10.97 ± 0.023[a]	10.98 ± 0.049[a]	11.31 ± 0.330[a]
C16:1	0.20 ± 0.001	0.19 ± 0.000	0.19 ± 0.001	0.20 ± 0.002
C17:0	0.07 ± 0.000	<0.07	0.07 ± 0.000	0.04 ± 0.001
C18:0	3.05 ± 0.007[b]	2.88 ± 0.010[d]	3.15 ± 0.003[a]	2.94 ± 0.150[c]
C18:1*trans*	nd	nd	<0.05	<0.01
C18:1 *cis*	17.07 ± 0.018[b]	16.05 ± 0.016[d]	17.44 ± 0.031[a]	16.72 ± 0.120[c]
C18:2	67.37 ± 0.001[c]	68.91 ± 0.105[a]	67.02 ± 0.162[d]	67.76 ± 0.240[b]
C20:0	0.17 ± 0.001	0.17 ± 0.002	0.18 ± 0.001	0.17 ± 0.003
C18:3	0.40 ± 0.002	0.42 ± 0.001	0.41 ± 0.001	0.43 ± 0.004
C20:1	0.10 ± 0.003	0.11 ± 0.001	0.13 ± 0.027	0.11 ± 0.002
C22:0	<0.07	nd	<0.07	0.03 ± 0.001
C24:0	0.08±0.000	<0.07	0.08 ± 0.000	0.05 ± 0.003
Σ Saturated	14.82	14.39	14.81	14.85
Σ Unsaturated	85.14	85.68	85.22	85.23

nd – not detected. Saturated –Sum of saturated fatty acids. Unsaturated – Sum of monounsaturated and polyunsaturated fatty acids. *Mean ± standard deviation - Means in the same row with different lower case letters are significantly different ($p < 0.05$) by Tukey's test,

Table 2. Oil yield, Oil recovery (%) and characteristics* of expeller pressed oil from different passion fruit manufacturers.

Parameters/Oil Characteristics	Passion Fruit Juice Manufacturers (PFJ)			
	PFJ 1	PFJ 2	PFJ 3	PFJ 4
Seed oil content (%) DW	32.0 ± 0.36[a]	32.4 ± 0.86[a]	27.6 ± 0.002[b]	28.0 ± 0.23[b]
Seed moisture (%)	7.1 ± 0.03[c]	6.9 ± 0.06[d]	8.3 ± 0.01[a]	7.2 ± 0.04[b]
Oil yield (%) DW	28.5 ± 0.24[a]	28.3 ± 0.63[a]	22.4 ± 0.54[b]	23.2 ± 0.97[b]
Oil recovery (%) DW	89.0 ± 1.04[a]	87.2 ± 2.52[a]	81.4 ± 1.82[b]	82.9 ± 3.25[b]
Outlet oil temperature (range, °C)	44 - 56	46 - 51	48 - 53	28 - 51
Cake oil content (%) DW	4.9 ± 0.09[a]	5.8 ± 0.12[a]	6.7 ± 0.86[a]	6.2 ± 1.26[a]
Oxidative stability (h)	8.2 ± 0.15[a]	6.5 ± 0.25[b]	8.8 ± 0.43[a]	6.9 ± 0.32[b]
Peroxide Value (mEq/kg)	0	0	0	0
Free fatty acids (%) as oleic acid	9.0 ± 0.21[b]	4.4 ± 0.04[c]	13.7 ± 0.21[a]	1.1 ± 0.06[d]
Oil moisture (%)	0.09 ± 0.001[a]	0.09 ± 0.002[a]	0.15 ± 0.003[a]	0.08 ± 0.003[a]
Conjugated diene (%)	0.20 ± 0.016[b]	0.16 ± 0.011[c]	0.25 ± 0.016[a]	0.16 ± 0.010[c]
Refractive Index (40 °C)	1.4667 ± 0[c]	1.4677 ± 0[a]	1.4607 ± 0[d]	1.4675 ± 0[b]
Relative Density (20 °C)	0.918 ± 0.0001	0.918 ± 0	0.917 ± 0	0.919 ± 0
Saponification Value (mg KOH/g)	193.4	193.2	193.4	193.4
Iodine Value (g I_2/100g)	132.6	134.5	132.4	133.1

*Mean±Standard deviation. Means in the same row with different lower case letters are significantly different ($p < 0.05$) by Tukey's test DW – Dry Weight.

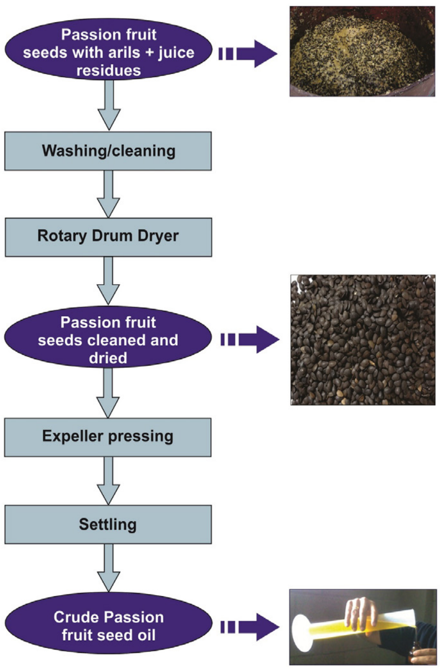

Figure 1. Flowchart of Passion fruit seeds processing.

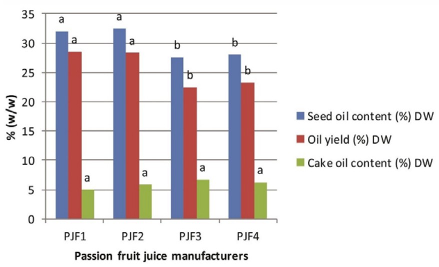

Figure 2. Oil Yield and cake oil content of expeller pressed seeds from different manufacturers of passion fruit juice (DW – Dry Weight).

3.2 Pressing of seeds with different moisture content

The expeller pressing of passion seeds withan oil content of 28.8% (dry basis) and moisture varying from 6.8 to 11.2% resulted in oil recovery decrease from 83% to 78% ($p < 0.05$) and oil yield from 24 to 23%, respectively. The higher cake oil content (8.3%) was obtained for the higher seed moisture process and it was possible to note the trend toward reduction of oil recovery and yield as seed moisture increased (Table 3 and Figure 3). Similar results were observed for screw pressing of crambe seeds by Singh et al. (2002), in which oil recovery increased as moisture seed content decreased from 9.2% to 3.6%. For Singh et al. (2012), depending on the pre-treatments performed on flaxseed before the screw pressing process, the oil recovery increased from 36.4 to 81% and the residual oil in cake reduced from 25% to 10% as moisture content decreased from 13.8% to 6.5%. The decrease of seed moisture resulted in an increase in oil yield and the highest values of oil yield were obtained with the lowest values of seed moisture for screw pressing of chia (Martínez et al., 2012). However, for screw press extraction of almond (53% oil) carried out by Martínez et al. (2013), the moisture content lower than 8% reduced the oil recovery. The oil yield obtained by industrial scale pressing of walnut and almond depended on the moisture content and the restriction die (Martínez et al., 2017).

Table 3. Oil yield, Oil recovery (%) and characteristics* of oil of expeller pressed passion fruit seed** with different moisture content.

Parameters/Oil characteristics	Passion fruit seed moisture (%)			
	6.8	**7.2**	**9.5**	**11.2**
Oil yield (%) DW	24.1 ± 0.13^{a}	23.2 ± 0.97^{ab}	23.3 ± 0.38^{ab}	23.0 ± 0.11^{b}
Oil recovery (%) DW	82.9 ± 0.41^{a}	82.9 ± 3.25^{a}	81.4 ± 1.27^{a}	77.9 ± 1.02^{b}
Outlet oil temperature (range, °C)	47 - 52	28 - 51	41 - 50	24 - 38
Cake oil content (%) DW	6.6 ± 0.21^{ab}	6.2 ± 1.26^{b}	6.9 ± 0.46^{ab}	8.3 ± 0.44^{a}
Oxidative stability (h)	7.4 ± 0.11^{a}	6.7 ± 0.06^{b}	6.8 ± 0.07^{b}	6.6 ± 0.07^{b}
Peroxide Value (mEq/kg)	0	0	0	0
Free fatty acids (%) as oleic acid	0.6 ± 0.06^{c}	1.1 ± 0.06^{a}	0.7 ± 0.02^{c}	0.9 ± 0.01^{b}
Oil moisture (%)	0.07 ± 0.007^{a}	0.07 ± 0.003^{a}	0.07 ± 0.004^{a}	0.08 ± 0.003^{a}
Conjugated diene (%)	0.16 ± 0.002^{a}	0.16 ± 0.006^{a}	0.15 ± 0.002 ^{a}	0.15 ± 0.013^{a}
Refractive Index (40 °C)	1.4667 ± 0^{a}	1.4677 ± 0^{b}	1.4677 ± 0^{b}	1.4677 ± 0^{b}
Relative Density (20 °C)	0.919 ± 0	0.919 ± 0	0.919 ± 0	0.919 ± 0
Saponification Value (mg KOH/g)	193.5	193.4	193.5	193.1
Iodine Value (g I_2/100g)	133.3	132.5	133.2	133.4

*Mean±Standard deviation. **Seed oil content = 28.8% (dry weight). Means in the same row with different lower case letters are significantly different ($p < 0.05$) by Tukey's test. DW – Dry Weight.

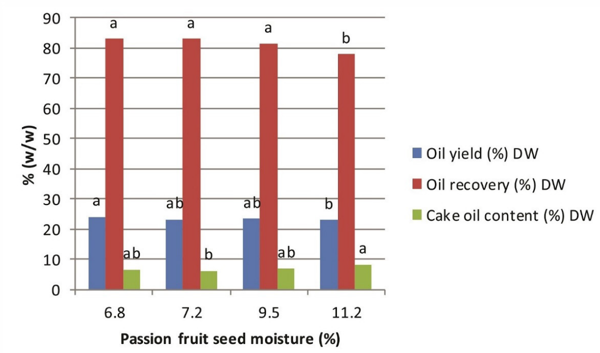

Figure 3. Oil Yield and cake oil content of expeller pressed seeds with different moisture content (%) DW – Dry Weight.

The data pointed out the feasibility of pressing conditions of cleaned and dried passion fruit seeds. The oil extraction efficiency observed for passion fruit seed was related to the presence of high content of insoluble dietary fiber (64.1 g/100 g) and total dietary fiber (64.8 g/100 g) as reported by Chau & Huang (2004). The high content of insoluble dietary fiber allows the compression of seed releasing oil. The increase in seed moisture promoted a softening effect, increasing the plasticity of passion seed and reducing the level of compression and friction, leading to lower oil yield. Screw pressing of sunflower achieved oil recovery of 49-65% (Pighinelli et al., 2009), whereas for peanut it varied from 21% to 44% leading to high a cake oil content of 22-44% (Pighinelli et al., 2008), despite the variation of moisture and temperature conditions used. Lower levels of insoluble fiber are observed for peanuts and whole sunflower seeds than for passion fruit seeds.

Screw press oil extraction and hydraulic pressing usually recover less than 90% of oil and are applied to seeds or nuts with oil content of 20% to 60%. Lower oil recovery may compromise the economic feasibility of raw materials with low oil content. The screw press of passion fruit seed (27% to 32% oil) resulting in a cake oil content lower than 10% has ensured the technical feasibility of the process. In a similar way, this was observed with lesquerella seed (28% of oil content), that after extrusion and expelling lead to an oil recovery of 72% to 81% and an oil content in press cake of 5.2 to 8% (Evangelista, 2009). Compared with other seeds, pressing of uncooked and cooked crambe seeds showed the cake residual oil content varying from 16.3 to 11.1%, respectively (Singh et al., 2002).

The outlet oil temperature varied among processes and a drop in temperature was observed for the higher seed moisture, presumably by reduction of friction as the moisture was increased. In order to reduce oil temperature during expeller pressing, the feed rate was reduced to less than the maximum capacity of equipment because an outlet temperature of 89 °C was reached by Wilhelm et al. (2014) with an increment of the feed rate of pressing from 1.2 to 3 kg/h of passion fruit seed.

Although no difference was observed for linoleic acid content (C18:2) (data not shown), OSI raised as the seed moisture was reduced and the higher OSI (7.4h) was observed for the oil obtained with 6.8% seed moisture ($p < 0.05$). Probably temperature lift during pressing promoted the extraction of compounds with a positive effect on oxidative stability. Low peroxide values were observed, indicating good initial quality. Therefore, high temperatures in oil extraction should be avoided, because of the low content of antioxidants such as delta tocopherol and gamma tocotrienol, which are around 120 mg/100g of passion fruit seed oil, as reported by Santana et al. (2015). High linoleic oils usually show lower figures of OSI than high oleic oils. However, Parker et al. (2003) reported that other compounds retained in the cold-pressing procedure may play a role in the oxidative stability of cold-pressed oils (cranberry, carrot, hemp caraway) besides the different levels of oleic, linoleic and linolenic acids observed. Rabadán et al. (2018) observed that the increase of the oil temperature during pressing raised the content of total polyphenols of walnut oils.

No differences were observed for conjugated dienes, oil moisture and peroxide value ($p > 0.05$) for oils obtained with different seed moisture. Variation in oil acidity was observed, but these figures were lower than the limit of Brazilian regulation for crude oils obtained by pressing (Brasil, 2021). Lower free fatty acid content was related to the lower seed moisture (Table 3).

The recovery of oils from fruit seeds increases the supply of vegetable oils rich in bioactive compounds for the cosmetics and functional foods market, as it is the case with commercially available passion fruit seed oil (Lucarini et al., 2019). The partially defatted cake obtained from pressing, besides being a source of fibers and proteins (Chau & Huang, 2004) can be used as raw material for the recovery of phenolic compounds (Viganó et al., 2016). The washing process performed before seed drying enabled the separation of aril fraction for further processing as a source of dietary fiber. The conducted processes allowed the recovery of by-products from the passion fruit production chain, thus reducing the environmental impact and generating products of commercial value.

4 Conclusions

The oil recovery higher than 81% and the lower cake oil content (5% to 8%) confirmed the feasibility of expeller pressing clean and dried passion fruit seeds in order to obtain high quality oil. The free fatty acid content varied from 1 to 14% depending on the passion seed manufacturers showing the need of by-product pre-treatment to improve the oil quality. The highest oil recovery (87% to 89%) was obtained for passion fruit seeds with higher oil content (32%). The oil recovery decreased (83 to 78%) as the passion fruit seed moisture increased from 6.8 to 11.2%, resulting in expeller pressed oils that met the requirements of Brazilian regulation regarding oil quality. The OSI of passion fruit seed oil from different manufacturers varied from 6.5 to 8.8 h and the highest OSI (7.4 h) and lowest free fatty acid content (0.63%) were obtained for the oil with the lowest seed moisture content. Although the outlet oil temperature reached 56 °C during pressing and the passion fruit seed oil contained high linoleic acid content (67%), peroxides were not detected which indicates that the employed conditions were favorable to obtain a high quality oil.

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