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PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIA DE ALIMENTOS

KELLY LIMA TEIXEIRA

INFLUÊNCIA DO MÉTODO DE SECAGEM NA QUALIDADE NUTRICIONAL, PROPRIEDADES BIOATIVAS E ANTIOXIDANTES DO FRUTO MOMORDICA CHARANTIA

SALVADOR

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Dissertação apresentada ao Programa de Pós-Graduação em Ciência de Alimentos (PGAli) da Universidade Federal da Bahia, como requisito parcial para a obtenção do título de Mestre em Ciência de Alimentos.

Drª Deborah Murowaniecki Otero
Orientador

SALVADOR

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TERMO DE APROVAÇÃO

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Aprovada em 27 de setembro de 2024.

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Dr. MARCELO ANDRÉS UMSZA GUEZ (EXAMINADOR)

Universidade Federal da Bahia (UFBA, BA).

Dedico este trabalho,

Aos meus pais, meus amigos e a minha orientadora que contribuíram para minha formação.

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Seja forte e corajoso! Não se apavore nem desanime, pois o Senhor, o seu Deus, estará com você por onde você andar (Josué 1:9)

RESUMO

O melão de São-Caetano (*Momordica charantia*) é um fruto não convencional, que apresenta uma diversidade de macronutrientes e micronutrientes. Possui alto teor de umidade, o que favorece a rápida deterioração. No entanto, processos de secagem podem aumentar sua vida útil e conservação, além de agregar valor à indústria alimentícia. Nesse contexto, este estudo teve como objetivos estudar o método de secagem mais apropriado para o fruto e analisar a composição físico-química, bioativa e antioxidante da casca e sementes do melão São-Caetano e suas possíveis aplicações em alimentos, através de uma revisão de literatura. Com base nos achados, a secagem por liofilização foi considerada o método de secagem mais eficaz para a conservação de nutrientes, em comparação aos métodos de secagem em estufa, infravermelho, micro-ondas e outros. Para além do artigo de revisão, foi realizada a caracterização do melão de São-Caetano quanto a caracterização físico-química, bioativa, atividade antioxidante e perfil de compostos voláteis. Os resultados demonstram que o melão de São-Caetano contém alto teor de proteína (13 a 15,3%), fibras (26,17 a 70,02%), minerais como o potássio (2.428,42 a 3.053,28 mg/100g), magnésio (6,47 a 6,61 mg/100g), ferro (10,30 a 12,77 mg/100g), manganês (5,50 a 7,35 mg/100g), cobre (0,52 mg/100g) e elevadas concentrações de ácidos graxos como o esteárico (41.97 %), oleico (7.00 %) e linoleico (6.53 %) na semente e vitamina C (27,78 mg.100 g^{-1} de ácido ascórbico) na casca. Maior atividade antioxidante foi observada nas sementes (53.550 µmol g^{-1}) em comparação à casca (39.67 mg.100 g^{-1}) devido à presença de compostos fenólicos e taninos hidrolisados. Maiores concentrações de carotenoides (115,47 mg g^{-1} de β-caroteno), flavonoides (21,64 a 49,26 mg QE g^{-1}) e taninos condensados (0,14 a 0,56 mg g^{-1}) foram obtidas na casca. Com a obtenção de farinha da casca e sementes do fruto, observou-se sua possível aplicação no desenvolvimento de novos produtos. Com base neste estudo, conclui-se que os frutos de *Momordica charantia* é um alimento não convencional com alto potencial de uso nutricional e tecnológico.

Palavras-chave: Melão de São-Caetano. Método de secagem. Macronutrientes. Compostos bioativos. Atividade antioxidante.

ABSTRACT

The melon of São-Caetano (*Momordica charantia*) is an unconventional fruit that presents a diversity of macronutrients and micronutrients. It has a high moisture content, which favors rapid deterioration. However, drying processes can increase its shelf life and conservation, in addition to adding value to the food industry. In this context, this study aimed to study the most appropriate drying method for the fruit and to analyze the physicochemical, bioactive and antioxidant composition of the peel and seeds of the melon of São-Caetano and its possible applications in food, through a literature review. Based on the findings, freeze-drying was considered the most effective drying method for nutrient conservation, compared to oven, infrared, microwave and other drying methods. In addition to the review article, the characterization of the melon of São-Caetano was carried out regarding physicochemical, bioactive, antioxidant activity and volatile compound profile. The results demonstrate that melon of São-Caetano contains high levels of protein (13.0 - 15.3%), fiber (26.17 - 70.02%), minerals potassium (2.428,42 a 3.053,28 mg/100g), magnesium (6,47 a 6,61 mg/100g), iron (10,30 a 12,77 mg/100g), manganese (5,50 a 7,35 mg/100g), copper (0,52 mg/100g) and high concentrations of fatty acids stearic (41.97 %), oleic (7.00 %) and linoleic (6.53 %) in the seed and vitamin C (27.78 mg.100 g^{-1} of ascorbic acid) in the peel. Greater antioxidant activity was observed in the seeds (53,550 µmol g^{-1}) compared to the peel (39.67 mg.100 g^{-1}) due to the presence of phenolic compounds and hydrolyzed tannins. Higher concentrations of carotenoids (115.47 mg g^{-1} of β-carotene), flavonoids (21.64 - 49.26 mg QE g^{-1}) and condensed tannins (0.14 - 0.56 mg g^{-1}) were obtained in the peel. By obtaining flour from the peel and seeds of the fruit, its possible application in the development of new products was observed. Based on this study, it is concluded that the fruits of *Momordica charantia* are an unconventional food with high potential for nutritional and and food use.

Keywords*: Melon of São-Caetano. Drying method. Macronutrients. Bioactive compounds. Antioxidant activity.*

SUMÁRIO

1 INTRODUÇÃO

Nos últimos anos, uma atenção crescente tem sido dada ao papel das frutas e vegetais na dieta e na saúde humana. O consumo desses alimentos tem mostrado uma correlação direta com estilos de vida saudáveis, o que pode estar relacionado a um padrão de dieta equilibrada, pois possui altos níveis de antioxidantes, compostos bioativos, além de macronutrientes, como gordura, proteína e carboidrato (Ferdaus et al., 2020).

Apesar da grande biodiversidade de frutos no Brasil, ainda existem espécies subutilizadas ou desconhecidas pela população, e são denominadas de Plantas Alimentícias Não Convencionais (PANC). Essas plantas podem contribuir para fortalecer a agricultura familiar, são fontes de nutrientes e seu cultivo pode ocorrer em regiões tropicais e subtropicais do mundo (Otero et al., 2020).

O melão de São-Caetano (*Momordica charantia* L.), geralmente conhecido como cabaça amarga, melão amargo, kugua, pêra de bálsamo ou karela, é classificado como PANC, pertencente à Família Cucurbitaceae (Yan et al., 2019). É uma planta provavelmente originária do sul da China ou leste da Índia, atualmente sua ocorrência principalmente em regiões tropicais e subtropicais da Ásia, América do Sul, África Oriental e Caribe, mas começou a ser cultivada em todo o mundo, devido ao seu uso culinário e medicinal (Hercos et al., 2021).

O seu consumo pode ser através cozimento, preparo de chás e molhos (Yan et al., 2019) e como ingrediente de pães e biscoitos quando transformado em farinha (Man et al., 2021). Inúmeros estudos científicos indicam que o melão de São-Caetano tem o maior valor nutricional entre outras frutas da família das Cucurbitáceas (Lubinska et al., 2020; Naik et al., 2022).

Geralmente esse fruto recém colhido possui alto teor de umidade e está suscetível a deterioração, causando perda de nutrientes. Com isso, o melão de São-Caetano requer secagem adequada para prolongar a vida de prateleira, e mantendo a qualidade. A secagem é uma tecnologia amplamente utilizada no processamento e conservação de alimentos, dentre eles podemos destacar secagem ao sol, secagem com infravermelho, liofilização, secagem com ar quente entre outros (Yan et al., 2019).

Sabendo-se que as características dos produtos após a secagem podem ser influenciadas pelos tratamentos utilizados. Para melhorar a qualidade do produto e aumentar a eficiência desse processo, é essencial avaliar o efeito da secagem nas alterações na qualidade e concentração de nutrientes (Feng et al, 2021).

De acordo com Calín-Sánchez et al. (2020), a liofilização é considerada um método eficaz por ser um processo de secagem a baixas temperaturas, colaborando para preservar uma maior quantidade de compostos nas amostras. Além disso, pode resultar em uma melhor eficiência de extração de fenóis, uma vez que durante a liofilização o desenvolvimento de cristais de gelo dentro da matriz da amostra pode causar rompimento das estruturas das células vegetais, o que pode permitir melhor acesso ao solvente e consequentemente melhor extração.

A partir de análises físico-químicas, bioativas e atividade antioxidante, observa-se que o melão de São-Caetano possui alto potencial alimentar por conter elevadas concentrações de fibras, proteínas, óleos essenciais, minerais, carotenoides, flavonoides e vitamina C (Otero et al., 2020; Man et al., 2021; Naik et al., 2022), contribuindo assim para a sua utilização como matéria-prima promissora para o desenvolvimento de formulações alimentícias (Hercos et al., 2021).

2 OBJETIVOS

2.1 Objetivo geral

- ✓ Avaliar a composição físico-química, bioativa e antioxidante da casca e sementes do melão de São-Caetano (*Momordica charantia),* além de identificar a influência dos métodos de secagem.

2.2 Objetivos específicos

- ✓ Elaborar um artigo de revisão integrativa compilando as informações existentes na literatura;
- ✓ Desenvolver uma farinha a partir do fruto (casca e sementes);
- ✓ Investigar a composição nutricional dos frutos do melão de São-Caetano;
- ✓ Pesquisar o potencial bioativo e tecnológico do fruto;
- ✓ Determinar a atividade antioxidante da *Momordica charantia L.* através de diferentes métodos;
- ✓ Identificar possíveis aplicações desse fruto na indústria de alimentos.

3 RESULTADOS

Como resultados da presente dissertação foram produzidos dois (2) manuscritos, um (1) de revisão de literatura e outro com análise em laboratório do objeto de estudo (Melão de São-Caetano), ambos em processo de análise em revistas internacionais.

Capítulo I

Manuscrito: Influence of the application of drying methods on the composition of different parts of the fruit of Momordica charantia: a comprehensive review

Influence of the application of drying methods on the composition of different parts of the fruit *of Momordica charantia*: a comprehensive review

Periódico a ser submetido (1ª submissão):	*Food Chemistry*
Maior percentil (Scopus):	*A1*
Periódico a ser submetido (2ª submissão):	*Journal of food compositionand analysis*
Maior percentil (Scopus):	*A2*

ABSTRACT

Bitter melon (*Momordica charantia*) is an unconventional fruit, which has nutritional and technological potential. It has a high moisture content, which favors rapid deterioration. However, drying processes can increase its useful life and conservation, in addition to adding value to the food industry. Thus, the aim of this study was to compile data on the nutritional composition, bioactive compounds, and antioxidant activity of *M. charantia* fruits dried by different drying methods, in addition to their technological potential through an integrative review. Bitter melon contains high levels of ash, fiber, protein, and fatty acids. Flavonoids, tannins, phenolic compounds, and vitamin C are responsible for the high antioxidant activity. Lyophilization drying was considered the most effective drying method for nutrient conservation, compared to oven, infrared, microwave and other drying methods. Therefore, it is of great importance to analyze the drying method to be used for this type of food, to obtain a better use of the fruit.

Keywords: Bitter melon; Lyophilization; Infrared drying; Hot air oven; Microwave; Ultrasound

1 INTRODUCTION

Nowadays, the demand for healthy foods has been growing, especially in relation to fruits and vegetables, which are sources of micro and macronutrients for the improvement and maintenance of human health (Mohammadi et al., 2020). Fruits and vegetables are responsible for around 22% of food losses and waste along the supply chain (not including the retail level). Numerous fruits, that are still little explored, have aroused the interest of researchers looking for products whose components can be incorporated to increase the quality of foods intended for human consumption (Bezerra & de Brito, 2020), as well as meeting current market demands.

However, fresh fruits are highly perishable products due to their high moisture content, which favors their deterioration in a short period of time. Nonetheless, these products can be dried and transformed into flour, increasing their conservation, in addition to adding value to the food industry, offering health benefits (Busuioc et al, 2020). Fruit flours also have important technological features and can be used as food ingredients, namely as thickeners, gelling agents, fillers, and water retaining agents, as well as in the production of edible films (Guarniz et al., 2019).

One of these promising fruits is the *Momordica charantia L.* (Jing-Kun et al., 2021) also known as bitter melon (Bezerra & de Brito, 2020), or bitter ground (Jing-Kun et al., 2021). *Momordica charantia L.* can be used both in culinary preparations and for medicinal purposes (Yan et al., 2019), due to the significant contents of proteins, essential oils, phenolic compounds and flavonoids, in addition to constituent esters and saponins to which their antioxidant characteristics are attributed (Jing-Kun et al., 2021). In turn, bitter melon has limitations due to its bitter taste, especially when eaten raw, which can be partially reduced when the fruit is dehydrated (Youn, Park, Yoon, 2019).

Drying fresh foods is an effective method widely used to reduce water activity, stop enzymatic reactions and microbial growth, resulting in extended shelf life and increased product safety as a food ingredient (Calín-Sánchez et al, 2020). Different drying techniques such as convective dryers, air circulation ovens, air jets, fluidized bed dryers and microwave ovens can be applied to remove moisture from fruits, which can affect the physical and chemical properties of the samples, influencing flavor compounds, phytochemical retention, and color (Yan et al., 2021).

In the drying process, different parameters can be controlled (air flow rate, temperature, final humidity of the process), which influence the quality of the flours (De Paula et al, 2019). Knowing the composition of the fruit and the particularities of the different drying methods are extremely important to evaluate their interactions on the compounds present in the fruit (Youn, Park, Yoon, 2019; Larrosa & Otero, 2021) and thus, devise strategies to minimize these losses.

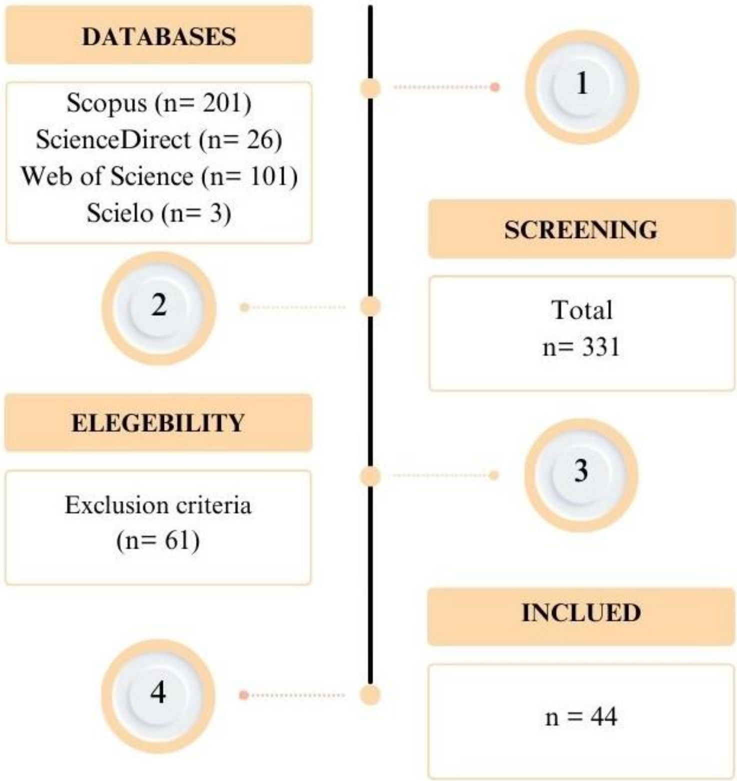
To date, there has been no published review covering all drying methods in relation to physicochemical composition, bioactive compounds and antioxidant activity. Given the above, this study aims to compile data on the nutritional composition, bioactive compounds, and antioxidant activity of *M. charantia L*. fruits dried through different drying methods, in addition to their technological potential through an integrative review.

2 MATERIAL AND METHODS

As a strategy for refining the research, combined keywords with different boolean operators and truncation techniques were used: "*Momordica charantia*" AND ("drying methods" OR "physical chemical composition" OR "antioxidant activity" OR "bioactive compounds" OR antifungal OR bactericidal OR application) AND NOT ("diabetic") AND NOT ("diabetes"). Among these, the use of the Boolean operators AND and OR is notable, as in the search process they function to find records containing all or any of the keywords separated by the operators. Additionally, parentheses "( )" were used around the keywords as a mechanism to guide the application regarding the order of priority in the search process.

The databases used for this study were Scopus, Web of Science, and ScienceDirect, along with the Scientific Electronic Library Online (SciELO). All studies containing the term *Momordica charantia* associated with drying methods, physical-chemical composition, antioxidant activity, bioactive compounds, or its application in the title, abstract, or keywords were selected for a detailed analysis. The steps developed in the methodology are summarized in Figure 1. In addition to the descriptor terms, other inclusion criteria were published articles from January 2018 to May from 2024 (the time frame was used to evaluate what has been studied recently), without any linguistic boundaries.

<**Fig. 1** Prisma of the review study screening process>.



3 RESULTS AND DISCUSSION

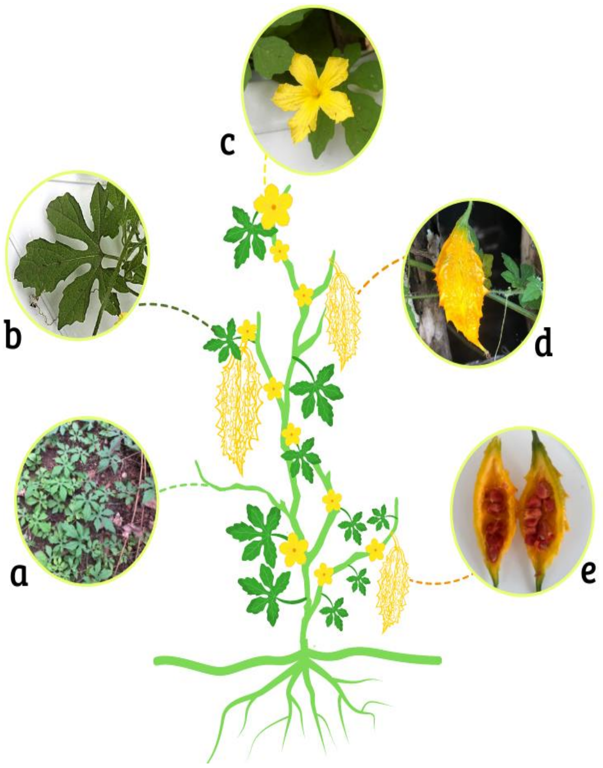
3.1 *Momordica* L., characteristics

A *Momordica charantia L*., known as bitter melon, bitter gourd (Li et al., 2021), balsamic pear, bitter cucumber or karela (Lin et al., 2020), is a plant belonging to the Cucurbitaceae family (Guarniz et al., 2019). Widely distributed in different parts of the world, this family has about 18 genera and 825 species, of which approximately 30 are cultivable, such as pumpkin (*Cucurbita spp*.), chayote (*Sechium edule*), watermelon (*Citrullus lanatus*) and melon (*Cucumis melo*) (Lubinska-Szcygel et al., 2019).

Bitter melon probably originated in the southern Indian state of Kerala, being introduced to China in the 14th century (Khan et al., 2020). Due to its use for culinary and medicinal purposes (Gao et al., 2019; Lubinska-Szczygeł et al., 2019), began to be cultivated also in South America, Africa, Australia (Alper & Cennet, 2022) and in other Asian countries (Ng & Kuppusamy, 2019; (IAL). In Brazil, the species was naturalized, being widely distributed in all regions (Oliveira, Filha, Lopes, 2020) and present in all Northeastern states (Flora do Brasil, 2020).

It is characterized as a subwoody climbing plant (Figure 2a) often found covering fences and bushes (Guarniz et al., 2019), in open areas such as orchards, coffee plantations and in vacant lots (Oliveira, Filha, Lopes, 2020). Its stem can reach up to five meters in length, being long and branched, grooved, with a greenish definition, with simple, long, and pubescent tendrils (Oliveira, Filha, Lopes, 2020). Its stem also has useful hairiness for water and protection against parasites (Lin et al., 2020).

<**Fig. 2** *Mormodica charantia L.*: a) Melon tree, b) Leave, c) Flower, d) Fruit, e) Open fruit with seeds>. Source: authors



The leaves have two greenish faces, with the side treated upwards being darker, the margin is jagged with irregular outlines (**Fig.** 2b) characteristics responsible for giving rise to the Latin nomenclature of the genus *Momordica* (bitten) (Yan et al., 2021; Oliveira, Filha, Lopes, 2020). The leaves also have five to seven lobes, with sharp apices and a straight petiole measuring two to three centimeters in length (Flora do Brasil, 2020).

Sprouting from the leaf axils, the bitter melon flowers (**Fig**. 2c) are found isolated, with five rounded yellow petals measuring about one centimeter (Silva, 2021). Contains small bright orange pistils and stamen in the center. They are monoecious flowers, with male and female flowers. The male flowers are solitary, on a peduncle with a reniform bract, glabrous or slightly pubescent, with an irregular lemon-yellow corolla. Females have long slender peduncles with bracts usually near the base (Oliveira, Filha, Lopes, 2020).

The fruit of *M. charantia* is similar to a cucumber (Oliveira, Filha, Lopes, 2020) (Figure 2d), with an oblong, fusiform and tuberculate shape (Flora do Brasil, 2020). The fruit skins are composed of a fibrous membrane and have long, soft protrusions (Lopes et al., 2020). When immature, they reflect a darker green color, with a more bitter taste, and when mature, they change to an orange-yellow color, with less bitterness. This taste is a result of triterpene glycoside (momordicosides K and L) and cucurbitacin-like alkaloids (momordicins I and II) (Lin et al., 2020).

When ripe, the fruit bursts open, displaying its seeds covered in red aril (**Fig.** 2e), with orange pulp (Oliveira, Filha, Lopes, 2020). These seeds are numerous, flat-shaped, oblong, bidentate at the base and apex and, when dry, have a grayish or cream color (Oliveira, Filha, Lopes, 2020).

Considering that the species adapts easily in regions with tropical and subtropical climates (Alper & Cennet, 2022), some of its characteristics can be modified depending on the geographic location (Lubinska-Szczygel et al., 2019), such as ripening time, growth, shape, size, color, shell texture (Lin et al., 2020), in addition to its bitter taste (Khan et al., 2020) and nutritional composition (Oliveira, Filha, Lopes, 2020).

3.2 Drying Methods

Numerous drying techniques have been developed and used to preserve plant products over the years. New emerging methods have been extensively studied in terms of chemical and biochemical variations in the product during the dehydration process, among which we can mention oven drying, microwave drying, infrared, freeze-drying, and others (Calín-Sánchez et al, 2020).

The characteristics of products after drying can be influenced by the treatments used. To improve product quality and increase the efficiency of this process, it is essential to evaluate the effect of drying on changes in quality and concentration of nutrients (Feng et al, 2021).

Removing moisture from fresh fruit inhibits the growth of bacteria and their proliferation, increasing the shelf life of the product. Furthermore, enzyme activity, sensory properties and microbial growth are also affected by the drying process. The drying mechanism consists of removing unbound moisture, followed by eliminating internal moisture. Even if surface evaporation occurs, it is crucial to also vaporize the delimited water, for only after the falling rate period is that the process results in a safe and dried product (Calín-Sánchez et al, 2020).

Thus, nutritional composition, bioactive compounds and antioxidant activity can be influenced according to drying methods, and they will be discussed in this article.

3.3 Nutritional Composition

Momordica charantia L. is among the best-known species of Cucurbitaceae due to its chemical potential (Busuioc et al., 2020; Ferdaus et al., 2020). According to the geographic location or method of analysis used, the fruits, pulp and seeds can vary in terms of their nutritional composition (Lubinska-Szczygel et al., 2019), presenting significant and variable amounts of lipids, carbohydrates, proteins, fiber, vitamins, and minerals (Mahmood et al., 2019; Jing-Kun et al., 2021).

In Table 1 are described the chemical characteristics and proximal composition of the fruit, peel and seeds of the melon and their respective drying methods.

Table 1. Proximal composition of *Mormodica charantia* unripe and mature.

	Unripe Fruit	**Unripe Peel**			
	Microwave (Ngueyen et al., 2020; Zahoor et al., 2023; Zahoor & Khan, 2019)	Drying at 105° C / (Youn et al., 2019; Yan et al., 2019)	Electric oven (Yan et al., 2019)	Lyophilization (Yan et al., 2019)	Infrared drying (Yan et al., 2019)
Moisture (%)	13.9	9.85 – 90.4	5.04	5.36	7.69
Protein (%)	-	-	4.08	7.30	1.83
Carbohydrate (%)	-	-	61.70	63.86	73.09
pH	5.4	-	-	-	-
Reducing sugar (mg/g)	36	-	-	-	-
Vitamin C (mg/g)	5.2 – 62.60	-	-	-	-
Vitamin A (U.I.)	9 – 140	-	-	-	-

	Mature Fruit					**Mature Peel**	**Mature Seed**
	Drying in the sun (Youn et al., 2019)	Hot air drying (Youn et al., 2019)	Lyophilization (Youn et al., 2019)	Infrared drying (Youn et al., 2019)	Drying at 70°C (Ferdaus et al., 2020)	Drying at 105°C (Hercos et al., 2021)	Drying at 105°C (Hercos et al., 2021)
Rehydration (%)	-	6.18	5.89	9.48	-	-	-
Moisture (%)	9.85	5.04	5.36	7.69	-	86.5	56.06

Ash (%)	-	-	-	-	0.92	-	-
Protein (%)	-	-	-	-	1.94	0.90	-
Total amino acids (g/100g DW)	1.088,37	1.007,78	1.211,88	1.123,84	-	-	-
Total essential amino acids (g/100g DW)	403.68	437.60	435.0	515.34	-	-	-
Total non-essential amino acids (mg/100g DW)	679.69	570.18	776.89	608.50	-	-	-
Lipid (%)	-	-	-	-	0.40	0.87	-
Carbohydrate (%)	-	-	-	-	3.07	-	-
Fiber (%)	-	-	-	-	3.06	-	-
pH	4.57	4.62	4.79	4.38	-	5.46	6.34
Titratable acidity (%)	0.63	0.61	0.60	0.69	-	2.85	2.04
Vitamin C (mg 100 g^{-1})	-	-	-	-	-	11.57	10.42

Total soluble solid (%)	1.26	1.12	1.27	1.12	-	-	-
Sugar content (mg/100d DW)	280.48	220.33	220.33	231.45	-	-	-

- analysis not performed by the authors

DW – dry weight

The different stages of maturation, as well as the different parts of the fruits experience changes in terms of the physical-chemical composition. The unripe bitter melon has higher humidity (~94.7 %) than the mature fruit (~90%) as shown in Table 1. The rind of the ripe fruit, in turn, presents moisture of 86.5% (Yan et al., 2019) while the seeds (ripe fruit) 56.06% (Jing-Kun et al., 2021). Foods belonging to the Cucurbitaceae family contain a high percentage of moisture and are prone to deterioration and nutrient reduction (TACO, 2011). Humidity is an important parameter for planning for the industry, preserving quality and extending the shelf life of foods (Jing-Kun et al., 2021).

Drying bitter melon is a strategy to reduce the water activity (A. w.) of the fruits and increase the possibilities of application and conservation. In the study by Yan et al. (2019) artificial methods were analyzed, such as in infrared radiation hot air drying (HD), vacuum drying (VD) and freeze drying (FD), all of which obtained values equal to 6%. The FD proved to be a superior method for obtaining high quality dry melon slices due to the preservation of the light green appearance. However, for HD and (infrared radiation) ID, the dry products showed yellowish colors compared to the FD samples, and most of the samples reduced in size. This color change may be due to enzymatic and non-enzymatic browning reactions that likely occurred when bitter melon was exposed to heat during HD and ID, allowing the products to turn brown and destroy the natural color (Yan et al., 2019).

The moisture found in fruits that used oven drying at 105°C obtained higher values when compared to other methods. Youn, Park and Yoon (2019) used ripe fruits and applied the methods of sun drying, hot air drying, lyophilization and infrared with results that varied between 5.04 and 9.85% (Table 1). The lyophilization and drying with hot air showed lower values of moisture content and there was no significant difference between the two drying methods.

Ngueyen et al. (2020) analyzed the unripe fruit and obtained a value of 13.9% moisture through the low temperature convective drying method and microwave radiation, and this process was interrupted when the moisture content of the slices approached 0.1 g water/g to guarantee the microbiological stability of the fruit.

The ash content represents mineral salts such as calcium, phosphorus, iron, zinc in the samples, and in fresh fruits they can vary between 0.30 and 2.10% (IAL). The value of this component found by Ferdaus et al. (2020) of ripe and fresh fruit was 0.92%. When comparing the mineral contents of melon with other fruits such as common passion fruit (0.20 to 0.40%) and melon passion fruit (0.60%) (De Paula et al, 2019) or with cucumber (0.27%), which belongs to the *Cucurbiataceae* family, (Gao et al., 2019) it is observed that the bitter melon has higher mineral contents (Table 1).

Yan et al. (2019) obtained different protein values and initially used three drying methods, namely freeze-drying, infrared and electric oven, with results ranging from 1.83 to 7.30%. This variation is due to the last two methods, where the green slices of bitter melon were subjected to high temperatures causing the denaturation of part of the protein in the sample. Therefore, the lyophilization method was the most effective for extracting this component. Corroborating this result, Jin-Kun et al. (Jing-Kun et al., 2021) found similar values (6.69%).

The protein content found by Ferdaus et al. (2020) was 1.94%, a higher value compared to mango (0.70%), guava (0.84%), papaya (0.70%) and banana (1.15%). Lower results were found by Piotrowski, Kostyra & Grzegory (2021) in orange melon with 0.60% protein. Hercos et al. (2021) analyzed only the peel biter melon and obtained 0.90%. Therefore, the fruit is a good source of this macronutrient, which can help in human health, since there are studies that prove its use in food, through application in drugs and nutritional supplements (Jha & Shimpi, 2018; Lin et al., 2020).

Regarding amino acids, the freeze-drying method obtained better results for total amino acids and non-essential amino acids, with values of 1,211.88 g/100g DW and 776.89 g/100g DW, respectively. Unlike the infrared method that obtained the highest value (515.34 g/100g DW) in the results of total essential amino acids. The reduction of amino acids in the other methods was due to thermal heat drying, which favored protein decomposition and loss (Youn, Park, Yoon, 2019).

Studies evaluating different drying methods for bitter melon are important to identify the bitter or sweet taste of the fruit. (Youn, Park, Yoon, 2019) found that the content of amino acids that produce a bitter taste when drying by infrared was higher, therefore it is considered undesirable. On the other hand, the amino acids that produced a sweet taste when freeze-dried were higher than with other drying methods.

Regarding lipids, it was the lowest value found in relation to macronutrients. In the ripe fruit and in the peel, values of 0.40% and 0.87% were verified respectively found similar values in orange melon (Piotrowski, Kostyra & Grzegory, 2021). Other foods belonging to the Cucurbitaceae family such as chayote, gherkin and cucumber have lower lipid levels than melons (Guarniz et al., 2019).

Plants have extracts and essential oils that can be alternative sources of unsaturated fatty acids (Mituiassu et al., 2021), representing a differential in terms of nutraceutical value. The amounts of compounds such as tocopherols in seed oils are generally correlated with relatively large amounts of unsaturated fatty acids (Yoshime et al., 2018).

The profile of fatty acids found in the seeds bitter melon indicate that the oil can be exploited as food sources for the organism. In seeds, stearic acid (18:0) and eleostearic acid (18:3) were the most abundant fatty acids, accounting for 37.60% and 39.16%, respectively. Palmitic acid (16:0) 12.36%, oleic acid (18:1) 8.71%, linoleic acid (18:2) 0.67% and gamolenic acid (18:3) 1.50% were present in less quantity (Zubair et al., 2018).

One of the methods used to remove the oil is cold extraction, as it is a fast mechanical process that does not require the use of organic solvents, allowing the conservation of essential characteristics (Yoshime et al., 2018). However, the seasons, climatic conditions and geographic locations can interfere with the qualitative and quantitative variation of the composition of this oil (Ramalingam et al., 2020).

For centuries essential oils from the seed of *M. charantia* have been traditionally used for the treatment of many pathologies (Ramalingam et al., 2020) such as: microbial infections, skin inflammations and aging, due to the synergistic activity of natural additives (Zubair et al., 2018). It also offers benefits to the plant itself by acting as allelopathic agents or as irritants that protect it from insect predation and parasite infestation (Ramalingam et al., 2020).

Carbohydrates are the most abundant macronutrients. The unripe fruit dried using different methods (HD, FD and ID) showed values from 61.70 to 73.09%, while the ripe fruit, using drying at 70°C, obtained only 3.07%. The discrepancy in these nutrient levels can be explained by geographical differences and soil conditions and stage of maturation. On the other hand, de Paula et al. (2019) identified results with lower values in cabotiá pumpkin (8.44 – 21.82%) which is part of the same family as bitter melon.

According to Souza et al. (2019) dietary fibers are present in foods of plant origin, mainly in fruits. Although they do not provide nutrients to the body, they are essential in the functioning of intestinal transit, reducing blood glucose and cholesterol levels. Ripe melon fiber content can reach 3.06% (Table 2), these values being higher than those found in traditional fruits such as mango (0.82%), banana (1.59%) and papaya (1.45%) (Ferdaus et al, 2020).

The pH value found by Yoon et al. (2019) in ripe fruits ranged from 4.38 to 4.79. Drying by hot air, lyophilization and infrared obtained the lowest values, since the Ph of lyophilization was the highest, with 4.79. The pH value found by Ngueyen et al. (2020) in the unripe fruit was 5.4, which can be related to the maturation stage, cultivation environment and drying method of the samples.

In contrast, Hercos et al. (2021) identified the Ph using the method of drying the samples at 70° C for peel and seeds of ripe fruits, and obtained results of 5.46 and 6.34 respectively, indicating that the peel is more acidic than the pulp.

According to Piotrowski, Kostyra & Grzegory (2021) some conventional fruits such as plum, pineapple, apple, passion fruit, strawberry and grape have higher acidity (pH < 4) compared to bitter melon. In terms of titratable acidity, infrared drying gave fruits greater acidity (0.69%), compared to the other methods described by (Youn, Park, Yoon, 2019). With drying at 70°C (Table 2), (Hercos et al., 2021) achieved higher values for the peel (2.85) and seeds of mature fruits (2.04).

Knowing that the pH is related to the acidity, the identification of these physical-chemical aspects is important to know the profile of sugars, acids and amino acids present in the fruits, as they interfere in the quality of the final product (Jing-Kun et al., 2021).

The soluble solids content (SST) was the highest at 1.27 ° Brix for freeze-drying, but there was no significant difference in the other drying methods. Generally, the higher the TSS values, the higher the extraction yield, increasing palatability and sweetness due to the high sugar content, contributing to better acceptability (Youn, Park, Yoon, 2019). This parameter is an indicator for evaluating the sugar content, but the TSS/TA ratio is fundamental in identifying the degree of maturation and flavor of the fruit (Piotrowski, Kostyra & Grzegory, 2021).

The reducing sugar results according to Youn, Park, Yoon (2019) were higher with sun drying (280.45 mg/g), unlike Ngueyen et al. (2020) who found only 36 mg/g using microwave drying. This parameter indicates the quality chromatic of the dry product, and the lower the sugar content, the more the non-enzymatic browning reaction is stimulated, and the color may become darker (Youn, Park, Yoon, 2019).

Regarding the results of Vitamin C, Hercos et al. (2021) achieved excellent results in the peel (11.57 mg 100 g^{-1}) and seeds (10.42 mg 100 g^{-1}) of melon. Busuioc et al. (2020) analyzed the juice of bitter melon using the whole fruit and obtained 23.9 mg 100 g^{-1}. Values higher than those found in plum, banana, apple and avocado (TACO, 2011). However, in green melon this result was significantly reduced after the microwave drying process (5.2 mg 100 g^{-1}). Thus, the analyzed ripe fruit can be considered a source of ascorbic acid. In the human body, this vitamin participates in the metabolism of iron, increasing its bioavailability, acting in the biosynthesis of collagen (Piotrowski, Kostyra & Grzegory, 2021), in addition to exercising an antioxidant function (Nguyen et al., 2020).

The Vitamin A content found in the unripe fruit was 140 I.U. In contrast, much of this vitamin was lost in convection drying ranging from 25.20 to 50.0 I.U. By raising the microwave power and temperature, it is possible to contain the maximum amount of vitamin A, since higher temperatures result in less reduction of vitamin A due to the increased solubility of beta-carotene at elevated temperatures (Zahoor & Khan, 2019).

3.4 Bioactive compounds

Bioactive compounds in the human body help the immune system, contributing to the treatment of pathologies. Specifically, they could inhibit oxidative damage from free radicals and oxygen-reactive species (Lee & Yoon., 2021).

The bitter melon has a variety of functional components, including flavonoids, polyphenols, glycosides, saponins, alkaloids, triterpenes, and steroids. Due to these functional components (Lee & Yoon., 2021), currently, research on these compounds have increased due to their medicinal potential (Prastiyanto et al., 2021). The values of bioactive compounds unripe and mature fruit are shown in Table 2.

Table 2. Bioactive composition of fresh *(Mormodica charantia)* unripe and mature fruit.

Unripe						
Analyzes	**Fruit**	**Dry Method**	**References**	**Peel**	**Dry Method**	**References**
Total Phenolic Compounds (mg/100g)	29.15 – 91.86 8.0	lyophilization microwave	Zahoor et al. (2023) Lopes et al. (2020), Nguyen et al. (2020)	-	-	-
Flavonoids (mg/100g)	-	-	-	85 – 108.94	lyophilization	Lubinska (2019)
Total Tannis (%)	-	-	-	0.27 – 0.99	lyophilization	Lubinska (2019)
Polyphenols (mg/g)	1.41 – 1.92 13.6 – 149.6	lyophilization, infrared, hot air oven ultrasound	Yan et al., (2019) Chakraborty et al (2020)	4.74 – 12.76	lyophilization	Lubinska (2019)

			Mature						
Analyzes	**Fruit**	**Dry Method**	**References**	**Pulp**	**Dry Method**	**References**	**Seed**	**Dry Method**	**References**
Total Phenolic Compounds (mg/100g)	10.45 25.85-27.42	lyophilization hot air oven	Alper & Cennet (2022) Pasakawee et al. (2018)	31.02 38.06-96.40	at 105°C lyophilization	Hercos et al. (2021) Lopes (2020)	55.75 12.25-59.89	at 105°C lyophilization	Hercos et al. (2021) Lopes (2020)
Flavonoids (mg/100g)	7.95 1.45 – 1.65 5.15 – 9.69	lyophilization sun drying, hot air oven .lyophilization; infrared; hot air oven	Alper & Cennet (2022), Youn et al. (2019), Pasakawee et al. (2018)	223.46	at 105°C	Hercos et al. (2021)	256.79	at 105°C	Hercos et al. (2021)
Carotenoids (μg/g)	-	-	-	21.49	at 105°C	Hercos et al. (2021)	10.54	at 105°C	Hercos et al. (2021)
Total Tannis (%)	-	-	-	0.54	at 105°C	Hercos et al. (2021)	1.24	at 105°C	Hercos et al. (2021)

Polyphenols (mg/g)	2.75 – 3.40	sun drying, hot air oven; lyophilization; infrared	Youn et al. (2019)	13.53 – 18.73	lyophilization	Lee & Yoon (2021)	-	-	-

- analysis not performed by the authors
DW – dry weight

Phenolic compounds are part of the largest group of secondary metabolites synthesized by plants and are known to exert antioxidant activity (Cuong et al, 2018), as they act by preventing cells against possible damage, including infections, radiation, and exposure to pollutants (Lee & Yoon., 2021). In the study by Lopes et al., (2020) the samples were lyophilized, and the extraction performed conventionally and by ultrasound. The concentration of phenols in the ripe pulp (96.40 mg/100g) stood out among all parts of the fruit, followed by the whole unripe fruit (91.86 mg/100g), both using ultrasound-assisted extraction. Unlike Nguyen et al. (Nguyen et al., 2020) who obtained lower values (8.0 mg/100g), using the microwave at low temperatures. In the mature fruit, (Passakawee et al., 2018) found values between 25.85 -27.42 mg/100g using the hot air-drying method at 50°C followed by cold extraction with the fruit. In contrast, (Hercos et al., 2021) employed the drying method at 105°C and achieved results ranging from 31.02 to 55.75 mg/100g.

Based on the results reported in the literature, it is suggested that the mechanism responsible for the destruction of phenolics was due to high temperature. Thus, it is suggested that shorter drying times, vacuum methods, and the use of pre-treatments can preserve more phenolic compounds, which is possibly related to the protection against oxidative reactions achieved when using such techniques (Reis et al., 2022).

According to Lin et al. (Lin et al., 2020) seven phenolic compounds were identified in bitter melon: *p*-coumaric acid, tannic acid, benzoic acid, ferulic acid, gallic acid, caffeic acid and (+)-catechin, the most predominant being acid gallic acid, followed by caffeic acid and catechin.

Another phytochemical found in abundance in melon are flavonoids, which are part of the group of phenolic compounds (Zahoor & Khan, 2019). Its classification is according to the natural pigments: anthocyanins, flavones, isoflavones, flavonols, flavanones and flavanes (Simonetti et al., 2021).

Hercos et al. (2021) analyzed the content of flavonoids in the peel (223.46mg/100g) and pulp of the ripe fruit (256.79 mg/100g), these concentrations being considered high, since conventional fruits have lower values, such as: jaboticaba (128 .3 mg/100g) and pitanga (95.9 mg/100g) (Youn, Park, Yoon, 2019) evaluated the flavonoid content through different drying methods (in the sun, hot air, freeze-dried and infrared) presenting values of 145 mg/g, 154 mg/g, 147 mg/g and 165 mg/g, respectively.

The predominant polyphenols of *Momordica charantia* are catechins, *p* -coumaric acid, tannic acid, ferulic acid, gallic acid and caffeic acid are known to have excellent antioxidant effects (Youn, Park, Yoon, 2019).

In relation to polyphenols, the ripe fruit was dried in the sun (2.75 mg/g), with hot air (3.40 mg/g), lyophilization (2.83 mg/g) and by infrared (3.13 mg/g), showing the highest value using hot air. The low content of polyphenols in the other methods was due to drying in the sun, which caused the oxidative destruction of this component under the interference of sunlight (Youn, Park, Yoon, 2019). More significant concentrations were found by Lee & Yoon (2021) in the rind of the ripe fruit (13.53 – 18.73 mg/g) using freeze-drying and then the ultrasound technique to extract these compounds.

The values obtained in the unripe fruit (4.74 – 12.76 mg/g) by Lubinska et al. (2019) were higher in the analyzes that used the methanolic extract. However, Chakraborty et al. (Chakraborty, Uppaluri & Das et al, 2020) performed the analyzes with ultrasound-assisted extraction and obtained superior results compared to Youn, Park &Yoon (2019) and Lubinska et al. (2019). Comparing the two modes, pulsed sonication was more effective for obtaining bioactive compounds, indicating that this methodology can be applied in aqueous extracts for future food and medicinal applications (Jha & Shimpi, 2018).

Yan et al. (2019) found results (1.41 – 1.92 mg/g) much lower than those previously mentioned, using other techniques (HD, FD and ID), being considered less efficient techniques for drying and preserving this component.

Carotenoids are known as nutrients that help in the functioning of some metabolic pathways to maintain human health (Yoshime et al., 2018), especially β-carotene (pro-vitamin A). It is present in fruits and vegetables, with a color that can vary from yellow, orange to red (Simonetti et al., 2021).

According to (Hercos et al., 2021) melon-of-São-Caetano presents significant values of this component both in the skin and in the seed (Table 2), as it has higher concentrations than cajá, jaboticaba, soursop, cupuaçu and açaí (Simonetti et al., 2021).

Regarding tannins, (Lubinska-Szcygel et al., 2019) reached lower levels (0.27 – 0.99) in the unripe fruit compared to (Hercos et al., 2021) who used the ripe fruit with drying of the samples at 105 °C and obtained 1.24% in the seeds and 0.54% in the peel.

The São Caetano melon is a fruit with numerous contributions to health due to its wide applicability. These bioactive compounds, as well as vitamins C and E, can act as free radical reducing agents, reducing metal ions that have been used to assess antioxidant capacity (Nguyen et al., 2020).

Momordica charantia is a fruit with numerous contributions to health due to its wide applicability. These bioactive compounds, as well as vitamins C and E, can act as free radical reducing agents, reducing metal ions that have been used to assess antioxidant capacity (Nguyen et al., 2020). This highlights the importance of choosing not only the analysis method, but also the best drying process for a given sample, to preserve the bioactive compounds (Reis et al., 2022; Wojdyło et al., 2019). According to Lopes et al. (Lopes et al., 2020) the optimization during the extraction process and the quantification method is essential for an accurate assessment of the content of phenolic compounds in different food matrices (Oliveira, Filha, Lopes, 2020).

3.5 Antioxidant capacity

The interest in bitter melon has been increasing due to the presence of antioxidant compounds, such as ascorbic and phenolic acids, flavonoids and carotenoids that offer benefits to human health (Jha & Shimpi, 2018)

These substances can be found in fruits and vegetables (Ng & Kuppusamy, 2019) and act by reducing the level of oxidative stress in cells, which is the main cause for the development of pathologies (Ferdaus et al, 2020). The results of the antioxidant activity, as well as the different drying methods performed on unripe and mature melon are shown in Table 3.

Table 3. Antioxidant activity of (*Mormodica charantia)* unripe and mature fruit and parts of the fruit.

Unripe

Analyzes	**Fruit**	**Dry Method**	**References**	**Peel**	**Dry Method**	**References**
ABTS (mg/mL)	1.64 – 1.74	hot air oven	Pasakawee et al. (2018)	1.35-3.96	lyophilization	Lubinska (2019)
ORAC (mg ET $^{-1}$)	53.87 – 4.65	lyophilization	Lopes et al. (2021)	-	-	-
FRAP (mg/mL)	3.0-3.48	hot air oven	Pasakawee et al. (2018)	9.38-25.90	lyophilization	Lubinska (2019)
DPPH (mg/mL)	3 – 3.48 14.27	hot air oven microwave	Passakawee et al. (2018) Nguyen et al. (2020)	0.93-2.60	lyophilization	Lubinska (2019)
CUPRAC (mg ET^{-1})	-	-	-	1.87-5.23	lyophilization	Lubinska (2019)

Mature

Analyzes	**Fruit**	**Dry Method**	**References**	**Peel**	**Dry Method**	**References**	**Seed**	**Dry Method**	**References**
Antioxidant activity (%)	-	-	-	9.06	at 105°C	Hercos et al. (2021)	75.89	at 105°C	Hercos et al. (2021)

ABTS (mg/mL)	0.881-0.981	lyophilization	Lee et al. (2017)	0.55-1.07	lyophilization	Lee & Youn (2021)	-	-	-
ORAC (mg ET $-^{1}$)	-	-		12.33-45.67	lyophilization	Lopes et al. (2021)	15.55-67.10	lyophilization	Lopes et al. (2021)
FRAP (mg/mL)	54.27-114.58	lyophilization	Perumal et al. (2021)	-	-	-	-	-	-
FRAP (mg/ ET^{-1})	57.32	lyophilization	Alper & Cennet (2022)	-	-	-	-	-	-
DPPH (mg/mL)	0.37-50.07	lyophilization	Lee et al. (2017); Perumal et al. (2021; 2022); Alper & Cennet (2022)	-	-	-	-	-	-

- analysis not performed by the authors
DW – dry weigh

*ET= Trolox equivalent

In general, the unripe fruit has the highest antioxidant activity, but the highest concentrations are found in the seeds (pulp) (Lin et al., 2020). According to Hercos et al. (2021), this factor can be attributed to the large amount of flavonoids, tannins and total phenolic compounds present in this part of the fruit.

Busuioc et al. analyzed the juice of *M. charantia*, where it showed high antioxidant capacity due to existing electron-donating compounds, such as polyphenols, which can transform free reactive species into non-reactive compounds, which are more stable. The high activation capacity of carboxyl groups indicates a strong ability to donate hydrogen atoms (Yan et al., 2021), which may favor the protection of biomolecules and prevent damage by free radicals (Chen et al, 2019).

It is of paramount importance to exist a balance between the production and neutralization of Reactive Oxygen Species (ROS) with antioxidant systems. If an imbalance occurs, cells can be exposed to oxidative stress due to increased production of this reactive species, causing metabolic disturbances in proteins, lipids, and nucleic acids (Alper & Cennet, 2022).

The antioxidant activity of bitter melon can also be explained by the presence of some acids. In the study by Alper & Cennet (2022) caffeic acid was determined as the major constituent in *Momordica charantia L.* extracts. It also stands out as a source of ascorbic acid and eleostearic acid that has shown inhibitory effects on cancer cells (Ng & Kuppusamy, 2019).

Even though there is no single method to assess antioxidant activity, usually two or more methods are combined in each study. The most used in food studies are 2,2-Diphenyl-1-picrylhydrazyl – (DPPH), [2,2′-Azinobis-(3-Ethylbenzthiazoline-6-Sulphonic acid)] – (ABTS), Fluorescence recovery after photobleaching – (FRAP), Antioxidant Reducing Capacity of Cupric Ions – (CUPRAC) and Absorption Capacity of Oxygen Radicals – (ORAC) (Reis et al., 2022).

The methods that are used to evaluate the antioxidant activity of fruits, when applied alone, may not provide safe and precise results, mainly due to the complexity of compounds with antioxidant capacity present in these vegetables. Due to the different types of radicals and the different sites of action, there is hardly a single method of analysis capable of representing in a safe and precise way the true antioxidant activity of a given substance (Otero et al., 2020).

Total phenolic content and flavonoids have been reported to be responsible for the antioxidant activities of melon extracts (Passakawee et al., 2018). In the ABTS analysis, the highest value found was in the unripe fruit using hot air oven drying (Passakawee et al., 2018), and the lowest value was in the ripe fruit using freeze-drying (Lee et al., 2017). Indicating that the maturation stage of the fruit may interfere with the levels of phenolic compounds, since the greater the amount, the greater the antioxidant activity.

According to Youn et al. (2019) hot air drying, and infrared drying showed significantly higher antioxidant activity than other drying methods. Showing excellent sensory quality characteristics during freeze-drying and showed high antioxidant activity during hot air drying and infrared drying.

Corroborating this result, Yan et al. (2019) analyzed the peel of the bitter melon fruit by different drying methods, and the antioxidant activity by ABTS decreased as the temperature increased among the drying methods. The process using hot air achieved better carotenoid retention and stronger antioxidant capacity compared to drying using heat pump dryer and freeze dryer for longer drying times.

Lyophilization is also considered an effective method according to Calín-Sánchez et al., (2020) because it is a freezing drying process at low temperatures, collaborating to preserve a greater amount of phenolics in the samples. In addition, it may result in a better phenol extraction efficiency, since during lyophilization the development of ice crystals within the sample matrix can cause disruption of plant cell structures, which may allow better access to the solvent and consequently better extraction

In the other analyzes (ORAC, FRAP, DPPH and CUPRAC) the studies showed that lyophilization proved to be a drying method with superior results for antioxidant analysis compared to other methods, such as oven or microwave drying. Consolidating with these studies, Piotrowski et al. (2021) analyzing strawberries observed that after lyophilizing them, they obtained fruits with less damage to the physical-chemical structure, and the lower the temperature and the longer the drying time, the more drastic the changes in the structure. The highest sensory quality was found in freeze-dried strawberries, the lowest in those dried by hot air drying.

The stability of compounds with antioxidant activity can be influenced by many factors, especially temperature, raw material, and process time. Although antioxidants are mainly lost during drying, it is essential to know the retention of antioxidant capacity for each drying technique to choose the one that provides high quality dry products (Calín-Sánchez et al, 2020).

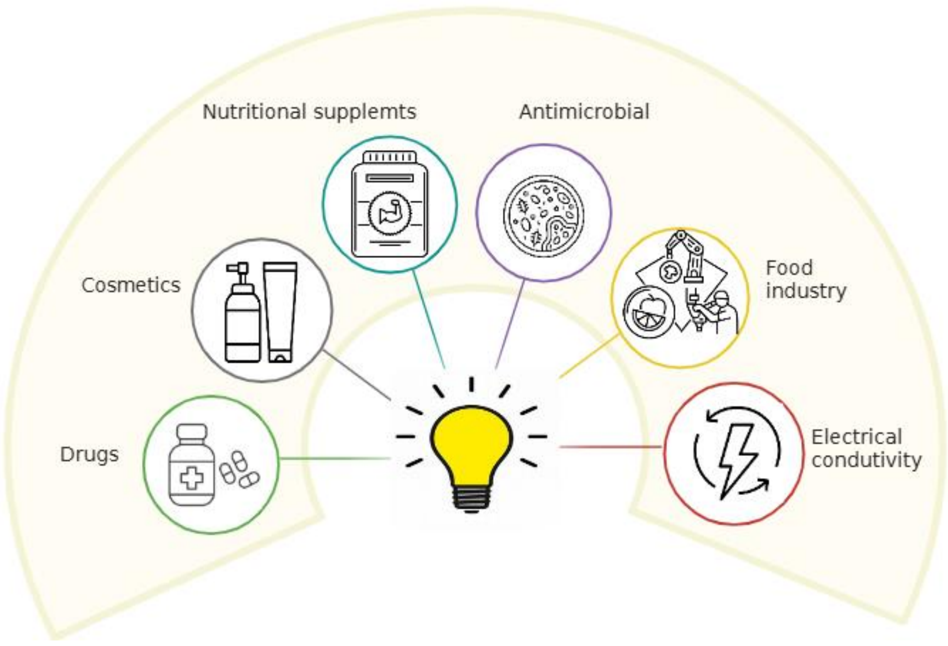
Recently, Kim et al. (2023) observed that after heat treatment, antioxidant activities increased with high drying temperatures, regardless of the fruit maturation stage. The results suggest that the color of the bitter melon and the processing temperature are the critical factors that increase the phenolic compounds and the antioxidant activity and that the ripe yellow fruit is better for consumption after the use of the thermal processing, being able to be used in industries of supplements and nutraceuticals.

The suitable drying method can be selected according to the type of food in addition to the processing purpose. It is of great necessity that sensorial tests be carried out due to the bitter taste present in the bitter melon. Its application in food industries can be expanded through studies on drying methods and the best way to use it.

3.6 Potential applications

The Cucurbitaceae family has numerous health benefits, and its nutritional and physical characteristics depend on the area of cultivation. All parts of the plant can be used for human consumption (Guarniz et al., 2019), in addition to applications in innovative technologies (**Fig. 3**) (Busuioc et al., 2020).

<**Fig. 3** Technological applications of *Momordica charantia.*>



Although they can be consumed in their mature or immature form (Oliveira, Filha, Lopes, 2020), the culinary use still has aversions when ingested due to its bitter and astringent taste (Youn, Park, Yoon, 2019).

Steaming the fruit is one of the healthiest methods of preparing food, preserving the nutrients and characteristic flavor, a good option in the processing of canned products, with the addition of seasonings to prepare with unique flavors (Yan et al., 2019). In India, for example, the fruit is used raw or cooked in the production of dishes and sauces (Lubinska-Szczygel et al., 2019).

The fruits are also consumed in their fresh form in the preparation of tea, wine, canned fruits, paste, fresh products (Yan et al., 2019), and in the production of yogurt, making it a functional beverage option due to its inhibitory activity of digestive enzymes and its antioxidant activity (Park, Lee, Kim, 2018).

As for the leaves and flowers, these can serve as an ingredient in drinks, as well as their seeds can be consumed in powder form (Jing-Kun et al., 2021) to take advantage of their nutraceutical properties for health (Yoshime et al., 2018).

The extract of bitter melon is becoming known in the production of natural organic foods, food supplements, as well as in the fortification of meats due to its nutritional and functional potential (Jha & Shimpi, 2018; Lin et al., 2020). The elaboration of flour is a viable alternative for conservation and extension of its shelf life, since melon is a food with a high moisture content that deteriorates quickly after harvesting, in addition to making it possible to consume it between harvests (Zahoor & Khan, 2019). Another recent technology studied by Gayathry and John (Gayathry & John, 2022) was nanoencapsulation, which can improve the stability of bioactive compounds when added to food or beverages, increasing the application possibilities of bitter melon.

In addition to the use of this fruit for food, studies report that *Momordica charantia* has been used in conventional therapy for various pathologies (Lee et al., 2017) in addition to contributing to improving immunity (Chen et al, 2021). In addition, it is known for its antibacterial, anti-inflammatory, antioxidant, anticancer, antiviral, anticancer, antileishmania, analgesic, hypoglycemic and hypocholesterolemic effects (Guarniz et al., 2019; Lee et al., 2017).

According to Yan et al. (Yan et al., 2019) *Momordica charantia* proved to be beneficial in the hypolipidemic effect with pretreatment in rats with myocardial infarction. Where there was a reduction in serum levels of triglycerides, total cholesterol, very low-density lipoprotein cholesterol and low-density lipoprotein cholesterol, and increased the serum level of high-density lipoprotein cholesterol, confirming its protective effect on health.

Melon can be employed as an antibacterial agent, especially for MDR strains of wounds. The methanolic extracts of the peel and pulp are effective against selected strains of fungi. The antimicrobial activity of essential oils has been known for many years and their preparations have wide application against microorganisms (Ramalingam et al., 2020) such as *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Salmonella typhi*, *MRSA* and *E. coli*. (Mohamood et al., 2019).

The use of *Momordica charantia* extracts showed larvicidal activity and can help to combat the agents that cause urban yellow fever, dengue, chikungunya and zika. Considering that these diseases are more common in urban centers and have rapid dispersion, this method can contribute to improving public health (Mituiassu et al., 2021).

Another technology using fruit extracts proved to be effective in the pharmaceutical industry as a form of lung cancer chemoprevention. The application of nanomaterials for the manufacture of a chemotherapeutic agent inhibited the apoptotic pathway of cancer cells, contributing to the treatment of this pathology that is recurrent worldwide (Hercos et al., 2021). Studies indicate that the oil may be beneficial in preventing diseases related to microbial infection, skin inflammation and aging, due to the synergistic activity of natural additives (Zubair et al., 2018). It also offers benefits to the plant itself by acting as allelopathic agents or as irritants that protect it from insect predation and parasite infestation (Ramalingam et al., 2020).

The Cucurbitaceae family has a vast economic contribution, including the cosmetic industry. Melon extracts are known for their calming, healing, and cooling properties; therefore, they are often added to skin care products (Busuioc et al, 2020). It is configured as an ingredient in sunscreens and cosmetics with UV filters (Jha & Shimpi, 2018).

The pericarp of *Momordica charantia* is used as a biosource of activated carbon, which is sustainable, has low cost and good electrical conductivity. Aparna, Ranga Rao & Tiju Thomas (Aparna, Ranga, Tiju, 2022) developed a device that delivers energy density of 23 Wh kg^{-1} at a power density of 900 W kg^{-1}. Indicating that activated carbon derived from melon pericarp is an electrode material to achieve high energy density, power density, eco-friendly and cost-effective supercapacitors.

Through solutions prepared with melon extract using the electrohydrodynamic method, electrosprayed fibers of gelatin and zein and electropulverized particles of maltodextrin are obtained. These particles can be added to foods to obtain better functional properties compared to traditional chemical additives, in addition to being an advantageous method for coating heat-sensitive materials (Besir & Kahyaoglu, 2020).

4 CONCLUSION

Currently, regarding food processing, several species of unconventional food fruits have been studied due to their nutritional and technological potential, aiming at the most diverse applications in industries. The choice of the drying method of the samples can influence the properties of the fruit, considering its nutritional composition and sensory characteristics. In the present study, freeze-drying presented better results regarding the analysis of the physical-chemical composition, bioactive compounds and antioxidant activity. Research like this can foster new perspectives and, therefore, stimulate the commercialization and consumption of this species, since its deterioration can occur due to the water present in the fruit. In addition to valuing and specifically understanding the benefits it can offer to health.

Author Contributions

Kelly Lima Teixeira- main author: Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft, Visualization. **Andrea Alves Seixas Lima**: Formal analysis. **Rita de Cássia Moura da Cruz:** Investigation. **Patrick da Silva Cardoso:** Writing - review. **Deborah Murowaniecki Otero:** Conceptualization, Supervision, Writing - review & editing.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the production of this article.

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Capítulo II

Manuscrito: **Nutritional, bioactive, and antioxidant properties of *Momordica charantia* fruit**

Nutritional, bioactive, and antioxidant properties of *Momordica charantia* fruit

Periódico a ser submetido (1ª submissão):	*Food Research International*
Maior percentil (Scopus):	*A1*
Periódico a ser submetido (2ª submissão):	*Plant Foods for Human Nutrition*
Maior percentil (Scopus):	*A2*

ABSTRACT

There is growing interest in investigating the benefits of Unconventional Food Plants (UFP) for use in the food industry. The melon of São-Caetano (*Momordica charantia*) is an unconventional fruit that presents a diversity of macronutrients and micronutrients. In this context, this study aimed to analyze the physicochemical, bioactive, and antioxidant composition of the pulp and peel of freeze-dried bitter melon and its possible applications in food. Melon of São-Caetano contains high protein (13,00-15,30%), fiber (26.17–70.02%), minerals potassium (2.428,42-3.053,28 mg/100g), magnesium (6,47- 6,61 mg/100g), iron (10,30 -12,77 mg/100g), manganese (5,50 -7,35 mg/100g), copper (0,52 mg/100g) and large amounts of fatty acids: acid glutamic (59,71-122,49 mg/100g protein), proline (54,46-59,86 mg/100g protein) and histidine 38,64-40,06 mg/100g protein), in the seeds. Higher antioxidant activity was observed in the seeds (53.550 µmol g^{-1}) compared to the peel (39.67 µmol g^{-1}), due to the presence of phenolic compounds (170.46-231.09 mg g^{-1}) and hydrolyzed tannins (0.99-1.10 mg g^{-1}). Higher concentrations of carotenoids (20.40–115.47 mg g^{-1} de β-caroteno), flavonoids (21.64-49.26 mg g^{-1}), and condensed tannins (0.14-0.56 mg g^{-1}) were obtained in the peel. By obtaining flour from the fruit's peel and seeds, its possible application in developing new products was observed. Based on this study, it is concluded that *Momordica charantia* fruits are an unconventional food product with a high potential for nutritional and technological use.

Keywords: Bitter melon; Proteins; Minerals; Bioactive compounds; Antioxidant capacity

1 INTRODUCTION

In recent years, there has been a gradual increase in consumer interest in including natural products in their diets, i.e., there is a greater concern with quality of life and good eating habits (Cyrille et al., 2024). The search for fruits rich in phytochemicals and with antioxidant properties is a continuous demand, due to their beneficial effects on human health (Lee et al., 2018).

Brazil is one of the world leaders in fruit production (Duarte et al., 2021), however, there are still few species explored or even completely unknown, and they are called Unconventional Food Plants (UFP). Studies have shown that the search for these species that are less known in nature and not sold in supermarkets is recurrent, but in most cases have food and nutritional potential (Otero et al., 2020). No reports were found in the literature on the quantity of production of this fruit in Brazil, as it is a plant that is not widely sold.

The melon of de São-Caetano (*Momordica charantia*) is a fruit that belongs to the UFP group, also known as bitter gourd, balsam pear, bitter melon, kugua or karela and belongs to the Curcubitaceae family (Man et al. 2021). It is characterized by elongated gourds or pits, similar to cucumber. It has an orange color on the skin and red seeds when ripe (Hercos et al., 2020). The fruits can be dried to produce flour, extending their shelf life, and can be used in the production of cookies, breads, and muffins (Man et al., 2021).

Like many plants, this fruit is rich in proteins, essential oils in the seeds, vitamin C, phenolic compounds, carotenoids, and flavonoids, influencing the antioxidant capacity (Lee et al., 2018). These nutrients have nutritional value inherent to their chemical composition and they may play a potentially beneficial role in reducing the risk of chronic degenerative diseases, such as cancer and diabetes, among others (Duarte et al., 2021).

These properties are usually related to chemical characteristics, which can interfere with nutritional and sensory properties, physical appearance, and ability to absorb water, among others (Santana et al., 2017). The study of the physicochemical composition, bioactive compounds, and antioxidant activity are of great relevance when considering the production and commercialization of food (Filho & Castro, 2020).

Considering the scarcity of scientific articles evaluating the nutritional and technological potential of *Momordica charantia* fruits, the present study had the general objective of analyzing the physicochemical, mineral, bioactive, antioxidant, and technological composition of the peels and seeds of melon of São-Caetano fruits collected in the interior of Bahia, Brazil.

2 MATERIAL AND METHODS

2.1 Sample

The fruit melon of São-Caetano (*Momordica charantia*) was collected in the city of Itaquara (Latitude: -13.446340, Longitude: -39.938132), Bahia state, Brazil. After collection, the fruits were washed and sanitized in chlorinated water (100 ppm) for 10 minutes. Then, they were rinsed with distilled water to remove chlorine residues. Only ripe fruits, with a yellow-orange color, were selected to be cleaned, separating the skin and seeds.

2.2 Drying the fruits

The pulp and peel of the fruit were frozen in an ultra-freezer at -80ºC. After 24 hours, the samples were freeze-dried (Terroni, LS3000) for 48 hours. At the end of the treatment, the freeze-dried seeds were ground and transformed into flour in a home blender (Philips Walita). The resulting sample was stored in hermetically sealed plastic bags without contact with light, at room temperature until further analysis, was performed at the Food Biochemistry Laboratory of the School of Nutrition of the Federal University of Bahia (ENUFBA).

2.3 Characterization of freeze-dried fruit

2.3.1 Physical-chemical determination

The determination of the moisture content of the samples was quantified using the oven drying method at 105º until reaching a constant weight. The ash content was determined using the muffle incineration method at 550º. Proteins were determined by the Kjeldahl method, with the samples being digested in sulfuric acid, the nitrogen to crude protein conversion factor adopted was 6.25, normally used to relate proteins from vegetables. The lipids were extracted in a Goldfish apparatus, using petroleum ether as the extracting solvent (AOAC, 2005).

Analyzes of pH, acidity, ºBrix, soluble solids content, and vitamin C were determined following the official methods of analysis of AOAC (2005).

The water activity (Aw) was evaluated manually, using a water activity analyzer (OEM, Model: HD-6). Analyses of neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed using the methods with the ANKOM system methodology (2012).

Carbohydrates were quantified by the difference between 100 and the sum of the percentages of moisture, proteins, lipids, and ashes. The total energy value was estimated by considering the conversion factors of 4 kcal/g for protein and carbohydrate and 9 kcal/g for lipids.

2.3.2 Mineral determination

For determination of Zn, Cu, Fe, Mn, Mg, Ca, K, and Na the digestion of the samples was carried out according to Doner & Age (2004), with some modifications. Seeds and peel (2 g each) were accurately weighed and put into a preheated muffle furnace, heated to 550 ºC, and kept at this temperature for 4 hours. After this time, 1 ml of nitric acid was added and the samples were placed on a hotplate until complete evaporation, returning for another 4 hours to the muffle.

This process was repeated until a total white ash was obtained. The residue was dissolved in 5 ml of 1% nitric acid, transferred, and swelled in a 10 ml flask. For Ca and Mn, at the end of the digestion, 1 ml of the sample, together with 1 ml of lanthanum oxide, were increased in a 10 ml flask (BRASIL, 2017).

Digested and diluted samples were stored in test tubes, under refrigeration, until reading. All the minerals were determined using a flame atomic absorption spectrometer (FAAS) (Varian, model AA 240 Fast Sequential) and expressed in mg/100g.

2.3.3 Color determination

The color of the peel and seeds of Melon of São-Caetano was determined using a colorimeter CILEAB (CR-400, Konica Minolta). In which, 5 color parameters were evaluated: L*, a*, b*, c*, and h*. The value of a* indicates the chromaticity in the region from red (+a*) to green (-a*). The b* value represents the range from yellow (+b*) to blue (-b*). L* provides the luminosity, which varies from white (L=100) to black (L=0). And finally, chromaticity (c*) and angle (hº) (Hunterlab, 1996).

2.4 Pulp lipid profile

The samples (peel and seeds) fatty acids were methylated according to Kramer et al. (1997). The resulting fatty acid methyl ester were determined using a gas chromatograph (model Focus GC; Thermo Scientific, Milan, Italy), equipped with flame ionization detector and fused silica capillary column SP-2560 (100 m x 25 mm x 0.2 μm of film thickness; Supelco, Bellefonte, Pennsylvania). Hydrogen was used as a carrier gas (1 ml/min) and nitrogen as an auxiliary gas. Detector and injector temperatures were set at 250°C, with split ratio 15:1. Oven temperature was set for 70°C for 4 min, increased by 13°C/min to 175°C, held for 27 min, increased by 4°C/min to 215°C and held for 31 min (Kramer et al., 1997). The FAME were identified by comparing three FAME references (Supelco FAME mix # C4-C24, CLA trans-9, cis 11 # 16413, and CLA trans-10, cis 12 # 04397; Sigma Aldrich). The cis/trans-18:1 isomers were identified according to their order of elution reported under the same chromatographic conditions (Kramer et al., 1997).

2.5 Amino acid profile

The determination of amino acids (peel and seeds) was done in according to Alves et al. (2022), with modifications. The sample was subjected to hydrolysis with 5 mL of 6 M HCl in autoclave. The residue was resuspended in ultrapure water, filtered and lyophilized again. The sample was resuspended in 1 mL of ultrapure water and injected in a liquid chromatograph.

The amino acids were identified and quantified in a high-performance liquid chromatograph (Shimadzu, LC- 20AD, Tokyo, Japan) coupled with a fluorescence detector and post-column derivatizer. The wavelengths for detection were 350 nm for excitation and 450 nm for emission. A Shim-pack Amino-Na Column (100 mm x 6 mm) was used, with elution of 45 min in gradient mode using two solutions prepared in Mili-Q water. The first consisted of 0.2 mol/L pH 3.2 citric acid buffer, the second of citric acid, boric acid and sodium hydroxide buffer both 0.2 mol/ L pH 10. The post-column derivatives were prepared from a solution of sodium carbonate (0.384 mol / L), boric acid (0.216 mol / L) and potassium sulfate (0.108 mol

/ L). In the first, 1% sodium hypochlorite was added and in the second, N-acetyl-L-cysteine and ortho-phthalaldehyde.

The identification of the amino acids was carried out by comparison of the retention times of aminoacid in the sample and the aminoacid in the standards solution. The quantification was estimated by the analytical curve of each amino acid. The amino acid standards used were aspartic acid, threonine, serine, glutamic acid, proline, alanine, cysteine, valine, methionine, isoleucine, leucine, tyrosine, phenylalanine, histidine, lysine and arginine; showed detection limits ranging from 0.07 to 16.6 ng mL-1 and linearity between 0.25 and 250 ng mL-1. The albumin solution (Bovine Albumin Inlab with 99% purity) was used as the primary protein standard.

2.6 Volatile compounds

The peel of Melão de São-Caetano were analyzed on a Shimadzu Nexis GC2030 gas chromatograph coupled to a mass spectrometer, equipped with an SH-Rxi-5Sil MS column (30 m x 250 µm, 0.25 µm) according to Alves et al. (2023). The samples were previously heated via headspace at 80 ºC for 30 min and a volume of 1.0 mL was injected into the chromatograph. The split mode was used with a ratio of 10:1 with a balancing time of 3 minutes.

The oven temperature programming was initially maintained at 50 °C for 1 minute, the heating ramp was from 5 °C/min to 150 °C, then increased to 10 °C/min to 240 °C. Helium 5.0 was used as the carrier gas, with a pressure of 4.7 psi, a flow rate of 0.94 mL/min, and a linear speed of 35.0 cm/s. The temperature of the injector, interface, and ion source was maintained at 250°C. The mass spectrometer operated in scan mode recording ions in the range of 20 to 400 m/z with a scan time of 150 ms and were compared with reference compounds from the NIST 17 library. The results were expressed in Area (%).

2.7 Solubility and absorption in water and oil

The water and oil absorption capacity was determined with modifications according to Filho et al. (2019). Around 2g of flour peel and seeds were mixed with 20 mL of distilled water or soya oil. That was followed by stirring and centrifugation (3000 x g, 10 min). After decanting the supernatant, the weight gain of the flour was expressed as water/oil absorption capacity in grams.

The solubility in water and oil was determined (Filho et al., 2019) from the supernatant liquid, carefully pipetted into Petri dishes, and placed in an oven at 105°C for 24 hours. After that period, the material was cooled in a desiccator and weighed on an analytical balance, the value obtained being the evaporation residue. The absorption capacity in water/oil (Equation 1) and solubility in water/oil (Equation 2) were calculated as follows:

$$\text{Absorption capacity in water/oil} = \frac{\text{Water or oil absorbed by the sample (g)}}{\text{Weight of dry sample (g)}} \qquad \text{Eq.1}$$

$$\text{Solubility in water/oil} = \frac{\text{Evaporation residue (g) x 100}}{\text{Weight of sample (g)}} \qquad \text{Eq.2}$$

2.8 Bioactive compounds

2.8.1 Preparation of extract

The extraction was performed with freeze-dried melon of São- Caetano (seeds and peel) with one solvent (ethanol 95%). Initially, 0,5 g of each sample was weighed and mixed with 20 ml of solvent, remaining in a water bath at 25°C for 24 hours (Solab, SL-154), under constant agitation. After that, the extracts were filtered with filter paper and stored in amber bottles, under refrigeration (- 18º C), until the following analyses were carried out. The extract obtained was used to analyze phenolic compounds, flavonoids, and tannins (Otero et al., 2020). All extractions were performed in triplicate.

2.8.2 Determination of the content of total phenolic compounds

The total phenolic compounds were determined according to Moo-Huchin et al. (2015), with some modifications. Briefly, 0.25 ml of the extract was mixed with 2.75 ml of 3% Folin-Ciocalteu solution. After 5 minutes of rest, 0.25 ml of 10% sodium carbonate solution was added, with a new rest of 60 min, in the dark, at room temperature. The reading was performed in a UV-Vis spectrophotometer Bel UV-M51 at 765 nm. The concentration of total soluble phenol compounds was calculated using a standard curve of aqueous and ethanol solutions of gallic acid (20 - 100 mg.L^{-1}) and expressed as mg gallic acid equivalents mg.g^{-1} dry weight (DW).

2.8.3 Determination of flavonoids

The flavonoid content was obtained according to the method proposed by Funari & Ferro (2006) with few modifications. 1 mL of extract was reacted with 3 ml of ethanol, 200µL of 2.5% aluminum chloride solution, and kept at rest for 40 minutes. Absorbance reading was performed using the UV-Vis spectrophotometer (Bel UV-M51) at a wavelength of 415 nm. Quantification was performed by using a standard curve on quercetin (0 to 100 mg.g^{-1}). Results were expressed as mg quercetin equivalents.g^{-1} dry weight (DW).

2.8.4 Determination of condensed tannins

Condensed tannins were determined using the methodology according to Price & Butler (1978). 100mg of sample was weighed and 10ml of 1% HCL in ethanol was added and centrifuged at 7000 rpm. The supernatant of the extract was collected and the vanillin solution 1:1 was added. The spectrophotometer was read at 500mn. The total concentration of condensed tannins was calculated using a catechin standard curve (0 - 0.0010 g.ml^{-1}). Results were expressed in milligrams of gallic acid equivalents per 100g of dry weight (mg.g^{-1}).

2.8.5 Determination of hydrolyzed tannins

The concentration of hydrolyzed tannins was determined 1g of sample was weighed, 25 ml of ethanol was added, and filtered through cotton. 0.3ml of the extract and 8ml of FAS solution were used (Brune, Hallberg, and Skanberg 1991). The spectrophotometer was read at 680mn. The concentration of total hydrolyzed tannins was calculated using a standard curve of aqueous and ethanol solutions of gallic acid (20 - 100 mg.L^{-1}), and it was expressed in milligrams of gallic acid equivalents per 100g of dry weight (mg.g^{-1}).

2.8.6 Determination of carotenoids

Analysis of carotenoid content was determined according to Rodriguez-Amaya (2001) with modifications. 0.5g of sample was weighed in triplicate, after which acetone. And petroleum ether was used in filtration. The reading was carried out at a wavelength of 450 nm. A calibration curve using β-carotene standard was constructed (50 mg L1), and the results were expressed in milligrams equivalent to β-carotene per 100g of dry weight ($mg.g^{-1}$).

2.9 Antioxidant activity

2.9.1 Preparation of extract

The antioxidant potential of the samples was determined using three different methods. The extraction was performed with freeze-dried seed and peel with solvent ethanol. Initially, 0,5 g of samples were weighed and mixed with 20 ml of solvent, remaining in a water bath at 25°C for 24 hours (Solab, SL-154), under constant agitation. After that, the extracts were filtered with filter paper and stored in amber bottles, under refrigeration (- 18º C), until the following analyses were carried out (Otero et al., 2020). All extractions were performed in triplicate.

2.9.2 Radical scavenging activity by DPPH• assay

The antioxidant activity of seeds and peel melão de of São-Caetano by DPPH [2,2-difenil-1-picril-hidrazil)] was determined according to Rufino et al. (2007), with slight modifications. The DPPH• solution was prepared with 2.4 mg of DPPH and 100 ml of ethanol mixed on the same day of the analysis. The absorbance reading was performed with the reaction mixture containing 50 µL of extract and 3.9 ml of DPPH• solution at 517 nm. A standard curve was obtained by using a DPPH standard solution within a concentration range from 10 to 100 $\mu mol.L^{-1}$, and the results were expressed as $mmol.g^{-1}$.

2.9.3 Radical scavenging activity by ABTS• assay

The antioxidant activity of pulp and peel Melon of São-Caetano was estimated by ABTS [2,2 -azinobis(3-ethylbenzotiazoline-6- sulfonate)] using the method described by Rufino et al.

(2007), with some modifications. The ABTS solution was prepared by mixing 5 mL of ABTS 7.0 mM solution and 88 µL of potassium persulfate 140 mM solution, which was left to react for 16 hours, at room temperature, in the dark. The solution was adjusted to the absorbance of 0.7 nm ± 0,05 nm at 734 nm. Then, 3.9 ml of ABTS+ solution was added at 30 µL of the sample, vortexed, and left in the dark at room temperature, resting for 6 minutes. The absorbance of each sample was measured at 734 nM absorbance. A standard curve was obtained by using Trolox standard solution within a concentration range from 0 to 2000 $\mu mol.L^{-1}$, and the results were expressed as $mmol.g^{-1}$.

2.9.4 Ferric reducing- antioxidant power (FRAP) assay

The antioxidant activity by FRAP scavenging assay was determined according to da Silva, Muniz & Nunomura (2013). The FRAP solution was prepared with 25 ml of acetate buffer 0.3 M, 2.5 ml of TPTZ 10 mM (2,4,6-Tris(2-pyridyl)-s-triazine) solution, and 2.5 ml of aqueous ferric chloride 20 mM solution, being made on the same day of analysis. 90 µL of the extract was added with 270 µL of distilled water, and 2.7 µL of FRAP solution, was stirred, and kept in a water bath at 37º C for 30 minutes. After this time, the reading was performed at 595 nm, using the FRAP reagent as a blank. A standard curve was obtained by using Ferrous sulfate 2mM standard solution within a concentration range from 100 to 2000 $\mu mol.L^{-1}$ and the results were expressed as $mmol.g^{-1}$.

2.10 Statistical analysis

The data were evaluated using different strategies in the Statistica software (version 7.0). Initially, the data were investigated for normal distribution using the Shapiro-Wilk test, and abnormalities ($p>0.05$) were corrected when necessary. They were then evaluated using the Student's t-test with 95% significance.

The data set related to bioactive and antioxidant activity was subjected to Principal Component Analysis and Factor Analysis, using Pearson's correlation matrix as a basis. Principal Components (PC) 1 and 2 were selected for analysis because they presented a total accumulated variance of 99.76%.

3 RESULTS AND DISCUSSION

3.1 Sample characteristics

Momordica charantia L. (Melon of São-Caetano or bitter melon) is one of the best-known and most studied species of the Cucurbitaceae family due to its high nutritional value (Busoioc et al., 2020). The fruit has an oblong shape, similar to a cucumber, is orange when ripe (Fig. 1 a) and weighs between 5.30±2.37g, has an average longitudinal axis of 39.61 mm and an equatorial axis ranging from 11.6 to 27.8 (Hercos et al., 2021). The seeds are red due to the presence of the natural pigment lycopene and some phenolic compounds (Fig. 1 b).

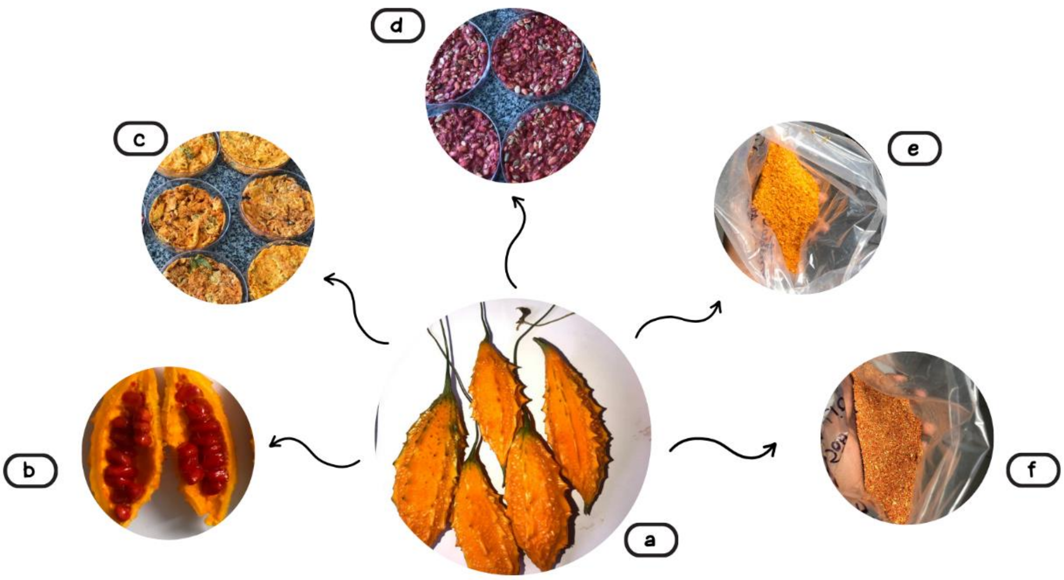


Figure 1. a) natural ripe fruit of the Melon of São-Caetano; b) opened fruit with seeds; c) freeze-dried peel; d) freeze-dried seed; e) crushed peel (flour); f) crushed seed (flour). Source: author himself.

Like other fruits, the bitter melon is also susceptible to deterioration due to excess water in its composition. Therefore, drying becomes a vital requirement to increase shelf life, maintain quality, and avoid nutrient losses (Yan et al., 2019).

Drying is a technology used in food processing and preservation to obtain dehydrated fruits for possible applications in the food and pharmaceutical industries. It consists of reducing the moisture content to a specific limit value for each raw material, which prevents its deterioration (Zahoor et al., 2019). In the study by Yan et al. (2019), it was concluded that freeze-drying *Momordica charantia* was a superior method to hot air drying and vacuum drying, as they obtained a high-quality product. In this article, the samples were freeze-dried separately, peel (Fig. 1 c) and seeds (Fig. 1 d).

Furthermore, as a pre-treatment, grinding the already dehydrated fruit into flour (Fig. 1 e; Fig. 1 f) can add value to the manufacture of new products, adding it to the preparation of purees, porridges, soufflés, among others (Yan et al., 2019). Contributing to the growing demand from consumers looking for foods with good nutritional quality and without additives (Zahoor et al., 2019).

3.2 Nutritional and physicochemical composition

The results of the physicochemical, centesimal, and mineral characterization of the skin and seeds of *Momordica charantia L* fruits are presented in Table 1 and expressed on a dry basis.

Table 1. Physicochemical, centesimal, and mineral characterization of the peel and seed of the freeze-dried Melon of São-Caetano.

Factor evaluated	Samples	
	Peel	Seeds
Moisture (%)	12,30 ± 0,49*	6,75 ± 0,99**
Ash (%)	15,98 ± 0,14*	2,31 ± 0,04**
Lipids (%)	1,81 ± 0,05**	10,86 ± 0,50*
Proteins (%)	13,60 ± 0,10**	15,30 ± 0,00*
Neutral fiber (%)	48,67 ± 0,28**	70,02 ± 0,61*
Acid fiber (%)	26,17 ± 0,28**	48,32 ± 0,73*
Carbohydrates (%)	56,31 ± 3,87**	64,83 ± 0,39*
Caloric value (Kcal)	279,32 ± 2,53**	418,26 ± 5,23*
Protein nitrogen (%)	10,23 ± 1,01**	16,97 ± 0,20*
Non-protein nitrogen (%)	1,08 ± 0,05**	5,59 ± 0,19*
Calcium (mg/100g)	184,02 ± 1,04*	66,51 ± 0,73**
Copper (mg/100g)	0,52 ± 0,08	0,52 ± 0,05
Iron (mg/100g)	10,30 ± 0,14**	12,77 ± 0,17*
Magnesium (mg/100g)	6,47 ± 0,19	6,61 ± 0,26
Manganese (mg/100g)	5,50 ± 0,15**	7,35 ± 0,11*
Potassium (mg/100g)	2428,42 ± 30,16**	3053,28 ± 47,89*
Sodium (mg/100g)	83,03 ± 0,74**	135,89 ± 9,26*
Zinc (mg/100g)	2,91 ± 0,03*	2,27 ± 0,18**
Acidity (%)	4,32 ± 0,22**	7,70 ± 0,66*
pH	5,59 ± 0,01*	5,76 ± 0,02**
Total soluble solids (°Brix)	5,33 ± 0,58**	9,67 ± 5,58*
Refractive index	1,34 ± 0,00**	1,35 ± 0,00*
aw	0,51 ± 0,00*	0,49 ± 0,00**

Vitamin C (mg.100 g-1 of ascorbic acid)	27,78 ± 2,44*	5,09 ± 0,68**
Colorimetric parameters		
L	53,11 ± 1,59*	38,32 ± 0,21 **
a	24,62 ± 0,64*	33,23 ± 1,07**
b	32,22 ± 2,89*	10,67 ± 1,19**
C	40,56 ± 2,66*	34,91 ± 1,24**
H	52,54 ± 1,88*	17,78 ±1,67**

The results were expressed as mean ± standard deviation. The results that presented significant difference ($p \leq 0.05$), according to Student's t-test, received different asterisks in the same line, with * being attributed to the highest mean and ** to the lowest mean. The absence of an asterisk in the same line indicates that there was no significant difference ($p > 0.05$), according to Student's t-test.

Moisture content plays an important role in determining the nutritional level of fruits, interfering with shelf life and microbial stability (Ferdaus et al., 2020). Hence, it is desirable to keep moisture as low as possible before storage (Naik et al., 2021). Dehydrated products in the form of flour of vegetable origin must have a moisture content of less than 15% (Santana e Silva et al., 2021) and in the present study, the highest moisture value was found in the peel with 11.14%, compared to the seeds (6.75%), thus complying with established standards.

Water activity (aw) also provides relevant data on the moisture content of the fruits. It is observed that the lower this activity, the slower the biochemical reactions and, therefore, the lower the mobility of the enzymatic activity. Water activity is classified as low moisture (aw up to 0.600), intermediate (between 0.600 and 0.900) and high (above 0.900). Both the peel (0.510) and the seeds (0.490) analyzed in this study, based on this classification, are considered to have low moisture (aw up to 0.600) (Filho & Castro, 2020).

The pH values found in this study ranged from 5.59 and 5.76 for the peel and seeds, respectively, and are considered slightly acidic. Similar values were found in the peel of the golden banana and the peel of the watermelon (Filho & Castro, 2020).

According to Ramos et al. (2020), determining the pH of foods is used as a highly important parameter, as it defines the rigor of industrial treatments, being selective in controlling the presence of microorganisms and the occurrence of chemical interactions, in addition to being a basic component of the taste of the food. Depending on the pH value, foods are classified as: slightly acidic (pH>4.5); acidic (pH between 4 and 4.5) and very acidic (pH<4).

Table 1 presents the colorimetric parameters of the flour peel and seeds of the melon of São-Caetano. In the L* coordinate, the skin of the melon of São-Caetano presented the highest luminosity of 53.11 (indicating a lighter tone for this part of the fruit), and the lowest L* for the seeds of 38.32. For the a* chroma, the seeds obtained high results (33.23) in relation to the shell, thus the red color of the lycopene present in the seeds contributed to this result. In the chroma b* of the peel (33.22), the yellow-orange hue was more predominant due to the high concentration of β-carotene (Hercos et al., 2020). Similar values were found in the mango peel (L* 55.11) and orange peel (b* 31.09) (Filho et al., 2020). The chromaticity (C*) was higher in the peel (40.56) than in the seeds (34.91), indicating that the seeds had a more intense coloration when compared to the peel.

Color has an impact on quality and consumer appreciation, who often prefer products with brighter colors (Filho et al., 2020). Luminosity (L*) is the attribute of colors on a flat surface, ranging from black to white. Saturation is also called Chroma (a* and b*), with varying intensities from green (-a*) to red (+a*), blue (-b*) to yellow (+b*), and these particularities are specific to each type of food. Other important factors in the colorimetric evaluation of a product are saturation (C*), which represents color purity, and hue (h°), which characterizes color quality (Filho et al., 2019).

Fruit color is an important quality factor, not only because it contributes to their good appearance, but also because it influences consumer choice. During ripening, most fruits undergo color changes, especially in the skin. Therefore, color becomes an important attribute in determining the ripeness stage of the fruits (Otero et al., 2020).

The seeds are the part of the fruit that stands out for containing the highest acidity (7,70%), while the peel obtained 4,32%. Similar values were found by Hercos et al. (2020) analyzing the fruit of *Momordica charantia*. This parameter is associated with pH, since the verification of these physical-chemical factors indicates a relationship with the balance between sugars, amino acids, and organic acids, and influences the quality of the fruit (Hercos et al., 2020).

The total soluble solids (TSS) and refractive index of the seeds presented higher values about the peel (Table 1). The TSS values measured by refractometry and expressed in °Brix are used as an index of total sugar in the fruits and their degree of maturity. This index represents an important quality attribute, thus contributing to the characteristic aroma of the juices. Therefore, there is a greater quantity of total sugar in the seeds (Souza et al., 2017).

The vitamin C content expressed in mg.100 g^{-1} of ascorbic acid found in the skin (27.78) of melon of São-Caetano was approximately 5 times higher than in the seeds (5.09). However, Zahoor et al. (2019) obtained even higher results in the whole fruit (29.96 to 37.06 mg.100 g^{-1}

of ascorbic acid), but this increase can be explained by the stage of ripeness of the fruit that was green.

The high vitamin C content, in addition to indicating the importance of the fruit as a supplier of an important nutritional compound, can also be considered a reducer of reactive oxygen species (Hercos et al., 2020).

The ash concentration was approximately six times higher in the peel (15.68%), and in the seeds 2.31%. Unlike Ferdaus et al. (2020) who obtained only 0.60% in the whole fruit melon of São-Caetano.

Table 1 shows the results obtained from the mineral analysis of the skin and seeds of the melon of São-Caetano. The most abundant mineral was potassium, in the peel with 2,428.042 mg/100g and 3,053.28 in the seeds, corroborating the findings in the studies by Mahwish et al. (2018) and Singla et al. (2023).

According to Krishnendu & Nandini (2016), the melon of São-Caetano has twice the calcium of spinach and twice the potassium of a banana, which are conventional foods. The peels of the fruit in this study obtained higher values of calcium (184.02 mg/100g) and potassium (2,428.42 mg/100g) compared to the peels of fruits such as soursop, jackfruit, sapodilla, lychee, mangaba, and cajarana (Bramont et al., 2018). Mahwish et al. (2018) found lower values in the rind of the São-Caetano melon, in the results of potassium (261.78mg/100g), iron (2.94mg/100g), sodium (73.28mg/100g), and zinc (0.68mg/100g).

Minerals are inorganic substances required in small quantities for the normal growth and functioning of the body and can be obtained from food sources such as vegetables and fruits (Cyrille et al., 2024). They are divided into two groups: macrominerals (potassium, magnesium, sodium, calcium, and phosphorus) and microminerals (manganese, zinc, iron, and copper), which play a significant role in several important biological processes for humans and plants. Unfortunately, food insecurity has become a global challenge for human nutrition to prevent mineral malnutrition in the population. One possible solution to this problem is to diversify the menu or implement biofortification of food products with parts of edible plants that are sources of these nutrients in the food industry (Singla et al., 2023).

The seeds of the fluted pumpkin fruit, which also belongs to the Curcubitaceae family, present lower mineral values (calcium: 128mg/100g; magnesium: 160.38mg/100g; potassium: 1057.23mg/100g; iron: 4.82mg/100g) (Cyrille et al., 2024) concerning the melon of São-Caetano.

Dietary intake requirements are a generic term for a set of nutrient reference values that include the Recommended Average Intake (EAR) and Adequate Intake (AI), and can be used to plan and assess the nutrient intake of healthy individuals (Singla et al., 2023). Based on these mineral references, the iron, copper, and manganese obtained from the analyzed fruit have levels above those recommended for adults, thus being a potential source of these nutrients. And Singla et al. (2023) recommend consuming whole fruits to obtain the benefits of macro minerals (especially Ca and K) as well as micro minerals.

Concerning fibers, two types were analyzed: neutral detergent fiber (NDF) and acid detergent fiber (ADF). The highest amounts of NDF (70.02%) were found in the seeds, followed by the peel with 48.67%. In the study by Duarte et al. (2021), lower values for NDF and ADF were found in the peels of apples, pineapples, bananas, and passion fruit. Fibers help with the consistency of foods, being a quality observed for inclusion in dietary preparations (Filho et al., 2019).

Carbohydrates are the most abundant macronutrients in the fruit, mainly in the seeds with 65.33% and the peel with 54.22%. Lower values were found in the peel of soursop (30.65%), lychee (25.53%) (Bramont et al., 2018), and tangerine (15.85%) (Ramos et al., 2020). Unlike Meneses et al. (2018) who found 74.96% of carbohydrates in the mango peel and Duarte et al. (2021) 85.48% in the pineapple peels. Reis et al. (2020) found lower carbohydrate values (25.67%) in the seeds of the Indian walnut, which is also rich in lipids.

The lipid concentration of melon of São-Caetano is in the seeds with 10.86%. A lower value was found in avocado seeds (2.34%) (Oliveira et al., 2021) and in watermelon only 2.79% of lipids. This macronutrient is part of a group of substances that are characterized by their high solubility in nonpolar organic solvents and low solubility in water, where the presence of fatty acids predominates in their composition (Duarte et al., 2021).

Regarding protein content, both the peel and the seeds obtained significant values, 13.0%, and 15.30% respectively. Otero et al. (2020) found similar results in these parts of the melon of São-Caetano fruits. Lower values were found in the mango peel (7.06%) (Meneses et al., 2018), soursop peel (1.62%), mangaba peel (0.78%), seriguela peel (0.73%) (Bramont et al., 2018) and watermelon seeds (2.07%) (Souza et al., 2019).

The values for protein and non-protein nitrogen are described in Table 1. Both the peel and pulp obtained good results for protein nitrogen, 10.23% and 19.97% respectively. The melon of São-Caetano flour can be incorporated into bread formulations to partially replace wheat flour without affecting its overall quality. The addition of this flour can increase protein content, but also mineral and fat concentrations when compared to bread made with wheat flour alone (Man et al., 2021).

Regarding the caloric value, the seeds of the melon of São-Caetano stood out with 418,26 calories, mainly due to the large amount of lipids in this part of the fruit. And in the peel, it obtained a lower value (279,32 kcal). Superior results were found in the mango peel (342.57 kcal) (Meneses et al., 2018), while the watermelon seed, obtained lower values (313.66 kcal) (Souza et al., 2019).

The protein analysis used in this study was through the Kjedahl method, which identifies the amount of nitrogen present in the samples. However, it is interesting to know whether the nitrogen found is of protein or non-protein origin. As mentioned above, several studies have described the high protein content in the fruits (peel and seeds) of *Momordica charantia*, but their protein and non-protein nitrogen content and complete amino acid profile are still unknown, and may be of interest for application in food and dietary supplements (Machado et al., 2020).

3.3 Fatty acid profile of seed

The analysis of the lipid profile of the seeds of the fruit of the present study is presented in Table 2. Stearic acid is predominant in this part of the fruit with 41.97%, followed by palmitic acid (8.35%) and oleic acid (7.0%). These acids have been increasingly used in various sectors of the industry, as they are constituents of vegetable oils. These components have high commercial value and can be applied in the food and cosmetic industries (Duarte et al., 2021).

The great expansion of the market has caused an increase in the productive demand for oils, as well as the need to optimize the process. From a health point of view, it is necessary to develop oils with a lower degree of installation to minimize damage to the health of the population (Araújo et al., 2019).

The quantification of free fatty acids in high-saturation oils indicates that they are less susceptible to deterioration, therefore it is one of the most important quality characteristics in the edible oil processing industries that need to be analyzed (Naik et al., 2021).

Table 2. Fatty acid profile of Melon of São-Caetano seeds.

Fatty acids (%)	**Seed**
Palmitic Acid (C16:0)	8.35 ± 0,09

Stearic Acid (C18:0)	41.97 ± 0,04
Oleic Acid (C18:1c9)	7.00 ± 0,76
Oleic Acid (C18:1c11)	0.23 ± 0,04
Linoleic Acid (C18:2n6)	6.53 ± 0,01
Alpha-Linoleic Acid (C18:3n3)	0.54 ± 0,08

The results were expressed as mean ± standard deviation.

They are frequently used as humectants, emollients, emulsifiers, and viscosity modifiers, which are associated with rejuvenating and healing properties, in addition to great nutraceutical potential (Araújo et al., 2019). In the study by Otero et al. (2020), the melon peel contained about 33% unsaturated fatty acids, of which oleic acid (C18:1) is in the highest concentration (19.6%), among the saturated fatty acids found (67%), heneicosanoic (C21) and palmitic acids (C16) were prevalent (22 and 25% respectively).

Nine types of unsaturated fatty acids were found in bitter melon extracts. The proportion of unsaturated fatty acid components in bitter melon is relatively high; monounsaturated fatty acids in the proportion of total fatty acid content are about 20.1%, while the content of polyunsaturated fatty acids is about 64.3% (Jia et al., 2017).

Samba et al., (2022) performed cold extraction of oil from *Mormordica charantia* seeds and showed good yield and oxidative stability, which can be explained by the presence of natural antioxidants such as tocopherols, sterols, carotenoids, and phenolic compounds.

M. charantia seed oil obtained at low temperatures has a higher saponification index. Therefore, this oil would contain more free fatty acids for stability during storage. This indicates a predominance of long-chain fatty acids in these oils, which is very important for the food and cosmetic industries. Oils with high saponification would be less susceptible to deterioration (Samba et al., 2022).

3.4 Amino acid profile of the peel and seeds

The results of the amino acid composition of the skin and seed samples of *Momordica charantia* fruits are presented in Table 3. The most abundant amino acids in both samples were glutamic acid, proline, and histidine. Branched-chain amino acids (leucine, isoleucine, and valine) are also present in substantial quantities, as well as arginine.

Table 3. Amino acid profile of the peel and seed of Melon of São-Caetano.

Amino acids (mg/100g protein)	**Samples**	
	Peel	**Seed**
Asparagic acid	31,67 ± 4,32	30,66 ± 0,49
Threonine	8,86 ± 1,27	7,99 ± 0,42
Serine	10,15 ± 0,93	7,97 ± 1,03
Glutamic acid	59,71 ± 8,87*	122,49 ± 9,73**
Proline	59,86 ± 3,40	54,46 ± 5,82
Alanine	30,01 ± 4,55	36,33 ± 4,85
Cysteine	31,40 ± 1,68	30,77 ± 3,94
Valine	13,52 ± 0,88	13,45 ± 0,66
Methionine	7,30 ± 0,62**	9,93 ± 0,84*
Isoleucine	6,62 ± 0,45**	8,34 ± 0,10*
Leucine	21,01 ± 1,91	21,63 ± 0,24
Tyrosine	8,26 ± 1,27	8,95 ± 0,77
Phenylalanine	8,92 ± 0,86	9,71 ± 0,17
Histidine	38,64 ± 1,46	40,06 ± 4,80
Lysine	19,37 ± 1,72*	11,11 ± 1,24**
Arginine	30,69 ± 2,18	28,65 ± 1,28

The results were expressed as mean ± standard deviation. The results that presented significant difference ($p \leq 0.05$), according to Student's t-test, received different asterisks in the same line, with * being attributed to the highest mean and ** to the lowest mean. The absence of an asterisk in the same line indicates that there was no significant difference ($p > 0.05$), according to Student's t-test.

Glutamic acid obtained the highest concentrations in this study, approximately 122.49 mg/100g in the seeds and 59.71 mg/100g in the shell. This amino acid is generally used in the intestine to produce adenosine triphosphate (ATP) for enterocytes. In addition to several beneficial functions in lipid and nitrogen metabolism, intestinal barrier function, antioxidant capacity and protects the body from damage caused by exposure to toxins (Chen et al., 2021).

Corroborating these findings, Aremu et al. (2019) analyzed the fruit of *Momordica charantia* and also found glutamic acid as the major acid. They found 46.28 mg/100 g of essential amino acids, and considered that these results are well above the 39% considered adequate for ideal protein foods for babies, 26% for children, and 11% for adults.

Proline was the second most abundant amino acid in the fruit of the melon of São-Caetano, with values of 59.86 mg/100g in the peel and 54.46 mg/100g in the seeds. Several studies indicate its use in the treatment of pathologies such as cancer, as it plays a role in protecting against oxidative stress, controlling apoptosis and osmoregulation (Choi & Coloff, 2019).

Aspartic acid, which obtained similar results in the peel and seeds, 31.67 mg/100g and 30.66 mg/100g, respectively. One of its characteristics is to restore the intestinal barrier, improving intestinal and hepatic energy metabolism (Chen et al., 2021).

Other amino acids that were found in lower concentrations are also important for human health. Such as arginine, which is an essential amino acid and helps in the growth of children. Isoleucine is an essential amino acid for the elderly and young people. Phenylalanine is the precursor of some hormones and the pigment melanin in hair, eyes and tanned skin. And tyrosine, although considered a non-essential amino acid, is the precursor of some hormones such as thyroid hormones and also melanin (Aremu et al., 2019)

Naik et al., (2022) report the relevance of amino acids present in protein extracted from melon of São-Caetano seeds, as it has the potential to be used as a protein source in many food formulations. From the extraction and characterization of protein from bitter melon seeds, it was reported that the protein fractions in this part of the fruit contain all essential amino acids. Therefore, they can meet the daily needs of preschool children (except threonine), in addition to being used as a thickener, flavor retention, and to improve the viscosity of several categories of food products.

The diversity of amino acids suggests their potential use in food products and dietary supplements aimed at improving cognitive and physical performance. Proline is important for the structure of collagen and branched-chain amino acids contribute to muscle growth. Glutamic acid, aspartic acid, arginine, and tryptophan are the main contributors to cognitive functions (Machado et al., 2020).

3.5 Volatile compounds

Volatile compounds are responsible for the aroma and flavor of foods. However, the chemical composition, including the concentrations of aromatic compounds, depends on the species and ripening stages. In addition, these substances give the fruit specific characteristics such as color and other properties that vary considerably from species to species, depending on climate parameters and soil conditions, especially during the plant's development phase during harvest (Carvalho et al., 2022).

In addition to the chemical composition, the volatile organic compounds (VOCs) present in the peel of the melon of São-Caetano were also analyzed. The results is shown in Table 4. Twenty VOCs were observed, with emphasis on Linalool, which obtained 37.75%

area. Almeida et al. (2024) also obtained similar results with the fruit of the São Caetano melon, also finding linalool as the major VOC.

Table 4. Volatile compounds of peel Melon of São-Caetano.

Volatile compounds	Area %
5-Hexen-2-ol, 5-methyl-	14.32
1-Butanol, 3-methyl-	21.27
Butanoic acid, 2-methyl-, methyl ester	5.15
2-Hexanol, 3,4-dimethyl-	2.71
Propanoic acid, 2-hydroxy-, ethyl ester	0.42
Methyl valerate	0.81
Acetyl valeryl	2.29
2-Hexenal	3.29
1-Hexanol	0.71
Butyrolactone	0.29
Hexanoic acid, methyl ester	0.69
Oxepine, 2,7-dimethyl-	1.06
Acetyl valeryl	0.95
2-Hexenoic acid, methyl ester, (E)-	4.67
5-Hepten-2-one, 6-methyl-	0.77
Furan, 2-pentyl-	0.90
Benzeneacetaldehyde	1.25
Linalool	37.25
Phenylethyl Alcohol	0.89
Butanoic acid, 3-methyl-, 1-ethenyl-1,5-dimethyl	0.31

Linalool is a monoterpene present in several plant species, such as bergamot, lavender, and mainly in lemon and orange. It is known for conferring important organoleptic properties (intense floral aroma) to citrus oils, and can be used as a fragrance fixative, in addition to having excellent pharmacological applications, such as anti-inflammatory, analgesic, vasorelaxant, and is also widely used in the agricultural area, due to its great antibacterial and antimicrobial properties in combating phytopathologies (Almeida et al., 2024).

In the study by Karatas and Ÿavsatli (2022) analyzing the fruit of *Momordica charantia*, it was found that the group of terpenes, to which linalool belongs, decreases its concentration in the fruit according to the progression of ripening. They also identified other compounds such as Alloaromadendrene, 10-β(H)-Cadina-1(6),4-diene, αCopaene, (E)-β-Ionone, and Valencen.

While the 16 VOCs identified by Lubinska-Szczygeł et al. (2019), β-citronellol, 1-hexanol, and 2-hexenal stood out. Linalool ranked 15th. The difference in the results found by

Lubinska-Szczygeł et al. (2019) and the present study can be justified as follows: even though they are the same fruit, the samples were collected in different regions (Brazil and Thailand), extracted with different solvents, and the temperature programming used in the chromatograph is not the same; however, these factors can influence the results (Carvalho et al., 2022).

It is noteworthy that this study is the first to investigate the VOC composition in the peel of *Momordica charantia* fruits in the Northeast region of Brazil and, therefore, has significant relevance.

3.6 Solubility and absorption in water and oil

Fruits are sources of nutrients that are highly appreciated by consumers. Dehydration can be used to obtain fruits with low moisture content and, consequently, to make flour. This product can be used as a raw material in the production of foods such as bread, crackers, and cookies. It can also be added as a complement to wheat flour. As a result, the demand for alternative natural products with functional characteristics for food production has grown (Filho & Castro, 2020).

The technological properties of flours can influence the physical appearance of the final food and are related to chemical components, such as proteins, for example, which have the ability to absorb water, form and stabilize emulsions, and provide solubility, among others (Santana et al., 2017).

Therefore, in addition to the physical-chemical characterization, the technological analysis of the powdered fruit is also interesting for possible applications in the food industry. The results obtained from the solubility and absorption in water and oil of the flour from the peel and seeds of the melon of São-Caetano are described in Table 5.

Table 5. Solubility and absorption in water and oil.

Evaluated factor	**Samples**	
	Peel	**Seed**
Water absorption (%)	5,14 ± 0,09*	2,33 ± 0,05**
Oil absorption (%)	2,49 ± 0,04*	1,01 ± 0,02**
Water solubility (%)	20,56 ± 0,76	19,04 ± 4,14
Oil solubility (%)	1,60 ± 0,09**	2,59 ± 0,04*

The results were expressed as mean ± standard deviation. The results that presented significant difference ($p \leq 0.05$), according to Student's t-test, received different asterisks in the same line, with * being attributed to the highest mean and ** to the lowest mean. The absence of an asterisk in the same line indicates that there was no significant difference ($p>0.05$), according to Student's t-test.

The water absorption of the flour from the peel of the melon of São-Caetano showed a significant difference compared to the flour from the seeds, 5.14% and 2.33%, respectively. Lower results were found in oat flour (0.85%) and wheat flour (1.15%) (Santana et al., 2017).

The water absorption capacity plays an important role in the texture of several foods, including ground meats and bakery doughs. Water imbibition without complete dissolution of the flour leads to an increase in properties such as consistency, thickening, viscosity and adhesion (Cyrille et al., 2024). This property in flours of vegetable origin is mainly attributed to the high fiber content normally found in this type of food (Santana et al., 2017).

In terms of oil absorption, the flour from the rind of the melon of São-Caetano also obtained better results, compared to the flour from the seeds. Lower values were found in passion fruit flour (2.35%) and grape flour (2.39%) (Santana et al., 2017).

The analysis of oil absorption is of great importance, since oil increases the soft texture in the mouth of foods, especially bread and other baked foods. The ability of this flour from the rind of the melon of São-Caetano to bind oil makes it very useful in food technology for oil retention and, therefore, may be suitable for retaining food flavors (Cyrille et al., 2024).

In relation to water solubility, both the rind and the seeds of the melon of São-Caetano presented similar values, 20.56% and 19.04%, and did not present a statistically significant difference. Santana et al. (2017) found values for golden and brown flaxseed flour, white beans, grapes and passion fruit, lower than those found in this study.

Flours with high water solubility values can be used in foods that require low temperatures to be prepared or as ingredients for the formulation of soups, desserts and sauces, which require ingredients with greater water solubility (Santana et al., 2017).

Only in the oil solubility of the seed flour (2.59%) of the melon of São-Caetano was the result superior when compared to the peel flour (1.60%). In summary, we understand that the application of flour products depends on their performance as a functional ingredient, as well as their technological behavior in food systems, ensuring that the products have quality and that they can aggregate the raw material in the most diverse types of foods (Filho et al., 2019).

3.7 Bioactive compounds and Antioxidant activity

The presence of bioactive compounds in the human body enables it to combat various lifestyle-related disorders. In particular, the ability of phenolic compounds to inhibit oxidation is the characteristic that prevents oxidative damage caused by various free radicals and reactive oxygen species. Recently, many studies have been conducted to identify food sources rich in antioxidants and separate bioactive compounds from natural sources (Lee & Yoon, 2021; Lopes et al., 2020).

Momordica charantia fruits are excellent sources of phenolics, flavonoids, tannins, and carotenoids. These phytochemicals exhibit various health-promoting effects, reducing the risks of chronic non-communicable diseases. Therefore, these phytochemicals are significant for food producers and consumers (Lee et al. 2017).

The bioactive compounds contained in melon of São-Caetano showed greater extraction efficiency when extracted using aqueous ethanol as a solvent, since the broken plant cell walls allow the solvent to penetrate the plant tissues, thus increasing the release of organic compounds from within the plant cells (Lee & Yoon, 2021). Therefore, ethanol was used for the extraction of bioactive compounds in the present study. The results of the analyses of total phenolics, carotenoids, flavonoids, condensed and hydrolyzed tannins are described in Table 6.

Table 6. Antioxidant activity and bioactive compounds.

Evaluated factor	Samples	
	Peel	Seed
DPPH (µmol g^{-1})	3.030 ± 0,08**	4.010 ± 0,06*
ABTS (µmol g^{-1})	18.38 ± 0,76	19.55 ± 0,68
FRAP (µmol g^{-1})	39.670 ± 0,41**	53.550 ± 1,21*
Total phenolics (mg GAE g^{-1})	170,46 ± 1,31**	231,09 ± 1,87*
Carotenoids (mg g-1 of β-carotene)	115,47 ± 1,90*	20,40 ± 1,92**
Flavonoids (mg QE g^{-1})	49,26 ± 0,51*	21,64 ± 0,35**
Condensed tannins (mg g^{-1})	0,56 ± 0,01*	0,14 ± 0,00**
Hydrolyzed tannins (mg g^{-1})	0,99 ± 0,01**	1,10 ± 0,01*

The results were expressed as mean ± standard deviation. The results that presented significant difference ($p \leq 0.05$), according to Student's t-test, received different asterisks in the same line, with * being attributed to the highest mean and ** to the lowest mean. The absence of an asterisk in the same line indicates that there was no significant difference ($p > 0.05$), according to Student's t-test.

In the present study, higher concentrations of total phenolics were observed in the seeds of the ripe fruit (231.09 mg GAE g^{-1}). Thus, the seeds can be considered a promising source of phenolic compounds, deserving attention in future studies. This is different from Pasakawee et al. (2018) who analyzed the green fruits of São Caetano melon and found lower concentrations. This can be explained by the ripening stage, ripe fruits have higher concentrations of phenolics than green fruits, due to the biosynthesis of phenolic compounds caused by enzymatic hydrolysis during ripening. And the main phenolic acids found were gallic acid, chlorogenic acid, catechin, caffeic acid, p-coumaric acid and ferulic acid (Lee et al. 2017).

The highest concentration of flavonoids is present in the rind of the melon of São-Caetano (49.26 mg QE g^{-1}), corroborating the findings of Otero et al. (2020). Unlike the study by Alper & Ozay (2022), they found lower values, only 7.95 mg QE g^{-1} of flavonoids in the fruit, which can be explained by the geographic location where the sample was collected. Flavonoids act as free radical scanners by chelating metal ions or suppressing the formation of reactive oxygen species, and can also regulate endogenous antioxidant defenses (Youn et al., 2019).

The carotenoids in the fruit peel have high concentrations (115.47 mg g^{-1} of β-carotene), compared to the seeds (20.40 mg g^{-1} of β-carotene). This was expected due to the orange color of the peel, unlike the seeds, which are red when ripe. Lower values were found by Lee et al. (2017) when they evaluated the carotenoid levels of melon of São-Caetano at different stages of ripeness. They observed that the variation between the reported values and the current findings may be due to different species or genotypes of the fruit. In addition, degradation, interconversion, or isomerization of carotenoids during transportation, extraction, analysis, and storage of fruits may also have contributed to the variation in carotenoid content, because these compounds are sensitive to light and heat.

The rind of the melon of São-Caetano is a source of carotenoids, with higher values compared to mango and pineapple (Hercos et al., 2021). These compounds act as coloring agents, precursors of vitamin A, and are antioxidants in biological systems. They offer a protective effect than dietary carotenoid supplements, increasing resistance to LDL oxidation, decreasing DNA damage, and inducing greater repair activity in humans (Ferdaus et al., 2020).

No results were found in the literature on condensed and hydrolyzed tannins in the fruit of the melon of São-Caetano. Analyzing the findings on tannins in the present study, it was found that condensed tannins are more concentrated in the peel (0.56 mg g^{-1}), while hydrolyzed tannins are in the seeds (1.10 mg g^{-1}). Although they are in low concentrations, they can form insoluble complexes with proteins, thus interfering with their availability. Therefore, it is also interesting to evaluate the protein digestibility of the fruit (Montes-Ávila et al. 2018).

Historically, tannins have been considered an antinutritional factor, but current information shows that their consumption has been bringing great health benefits as bioactive compounds. Therefore, the adequate use of tannins requires more information about the exact chemical composition of each food. In addition to other relevant factors, such as the identification of tannin-resistant bacteria involved in intestinal metabolism, the role of bacterial metabolites, evaluation of the biological activity of tannins, among other aspects (Montes-Ávila et al. 2018).

These compounds are water-soluble and have the ability to form water-insoluble complexes with proteins, gelatins, and alkaloids. The content of phenolic compounds can vary in different parts of the fruit, especially when comparing the skin, pulp, or seeds. However, in excess, they can significantly reduce the mineral bioavailability and protein digestibility of the food (Tebaldi et al., 2019).

On the other hand, some studies indicate that condensed tannins can help in the protein absorption made by the organism of animals. Hydrolyzed tannins have beneficial effects on human health, acting as antimutagenic, anticancer and antioxidant. In addition to reducing serum cholesterol, triglycerides and suppressing lipogenesis by insulin (Das et al., 2020)

Tebaldi et al. (2019) analyzing the red raw melon, also from the Curcubitaceae family, observed the presence of tannins only in the fruit's peel. Hercos et al. (2021) found the percentage of total tannins in the peel and seeds of melon of São-Caetano to be 0.54% and 1.24%, respectively.

In this context, we observed that the analyzed extracts of melon of São-Caetano contain natural antioxidant substances and can be used as antioxidant agents in specific food products (Lubinska et al., 2019). Thus, the antioxidant potential of the seeds and peel of this fruit can be attributed to the high concentrations of flavonoids, carotenoids, tannins and total phenolic compounds.

The different antioxidant tests (DPPH, ABTS and FRAP) were performed with ethanolic extracts, since ethanol offers an advantage due to its safety for applications in food and human consumption (Lopes et al., 2020). Table 5 describes the results of the three methods of antioxidant activity for the peel and seeds of melon of São-Caetano. Regardless of the methodology used, the seeds presented greater antioxidant activity, which may be related to the higher content of natural antioxidants such as phenolic compounds and lycopene. However, the peel showed higher concentrations of carotenoids, flavonoids and vitamin C that act as reducers of reactive oxygen species, influencing the antioxidant activity of this part of the fruit (Hercos et al., 2020).

The FRAP method was the one that showed the highest values of antioxidant activity, both for the seeds (53,550 µmol g^{-1}) and for the peel (39,670 µmol g^{-1}). In the findings of Nguyen et al. (2020) analyzing the antioxidant activity in *Momordica charantia* fruits, they also obtained higher results in FRAP when compared to DPPH. Indicating that for this type of sample, FRAP is capable of interacting with more compounds present in the fruit and thus measuring a greater antioxidant capacity.

The FRAP method is widely used to measure the antioxidant capacity of fruits (Otero et al., 2020) and is based on electron transfer, that is, it measures the capacity of the antioxidants contained in the solution to reduce iron (Fe3+) to the iron Fe2+ form, which is complexed with TPTZ (Fe2+ - TPTZ). The increase in absorbance due to the formation of the Fe2+ - TPTZ complex is proportional to the antioxidant power of ferric reduction of the antioxidants present in the sample evaluated (Kessin et al., 2018). This high result may be due to the high concentrations of iron in the fruit, especially in the seeds (12.77 mg/100 g).

This is different from the study by Lubinska et al. (2019), where the FRAP method achieved the lowest antioxidant capacity results in melon of São Caetano fruits compared to ABTS. This can be explained by the use of solvents (water and methanol) used for extraction, influencing the amount of substances obtained.

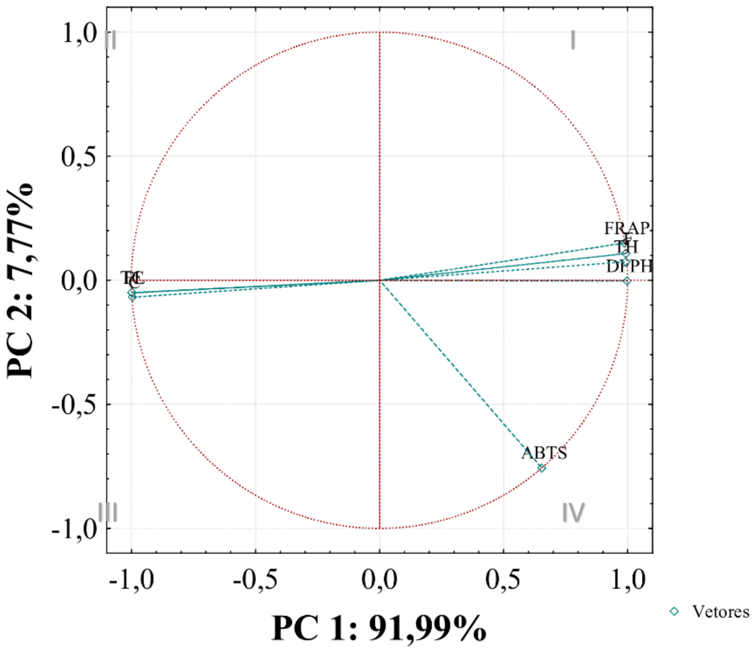
The results of the antioxidant capacity by the ABTS method were approximately 5 times higher than those found for DPPH. The DPPH test is based on measuring the antioxidant capacity of a given substance by donating an unpaired electron or hydrogen atoms, stabilizing the DPPH radical and the antioxidant substance (Lopes et al., 2020). A similar mechanism is evaluated through the ABTS method, which allows the evaluation of antioxidant activity by capturing the ABTS radical, generated through a chemical reaction, compared with a standard antioxidant (ascorbic acid or Trolox) in a dose-response curve (Kessin et al., 2018).

According to Lubinska et al. (2019) analyzing the antioxidant activity of two varieties of *Momordica charantia* fruits, the lowest value found was in DPPH, as in the present study. Indicating that the extracts of the large and small fruits of the melon of São-Caetano have slow-rate free radical scavenging agents, in relation to the DPPH• radical.

With the correlation and principal components analysis, it was observed that the *loadings* (Figure 2a) show an antagonistic effect for the vectors of quadrants I and III (Figure 2a), according to the angle of approximately 180° between the vectors. This behavior indicates that a greater antioxidant activity was observed in the seeds compared to the peels for the DPPH• and FRAP radicals, in addition to higher concentrations of phenolic compounds and hydrolyzed tannins. In the peels, carotenoids, flavonoids and condensed tannins had higher concentrations compared to the seeds. Similar results were found by Otero et al. (2020) analyzing the peel and pulp of melon of São-Caetano fruits.

Considering the loadings (3a) and scores (1b) under the factorial design, it was shown that the antioxidant activity in stabilizing the ABTS•+, DPPH• and FRAP radicals was associated with the presence of phenolic compounds and hydrolyzed tannins in the melon of São Caetano seeds, according to the position of the respective vectors in quadrants I and IV. These findings corroborate the study by Pasakawee et al. (2018), where they correlated these compounds with ABTS•+ and DPPH by analyzing *Momordica charantia* fruits.

(a)



(b)

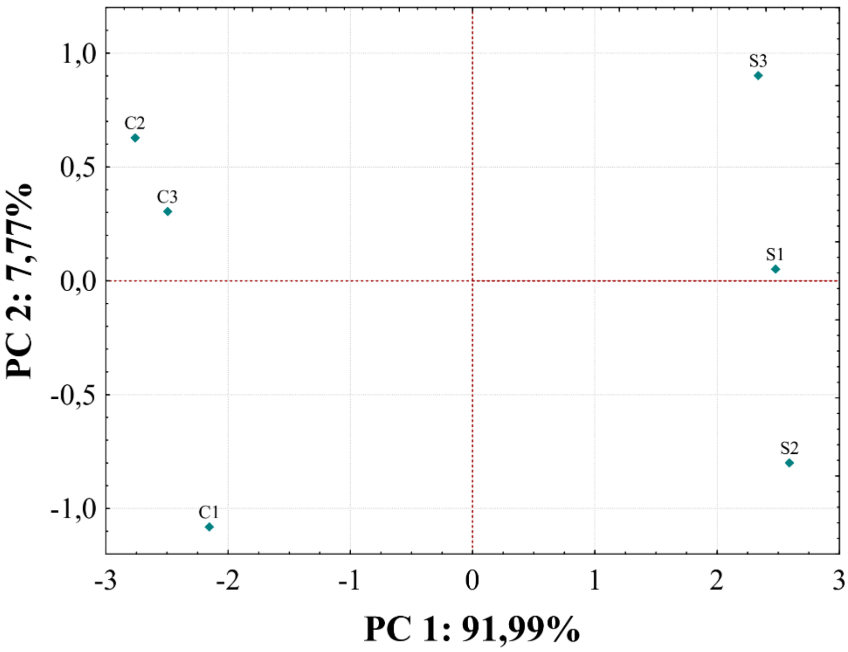


Figure 2. Evaluation of bioactive compounds and antioxidant activity of Melon of São-Caetano peel and seed by Principal Component Analysis and Factor Analysis.

Em *loadings*: FRAP, DPPH - DPPH• hydrolyzed tannins– TH e Flavonoids – F (**quadrante I**); carotenoids – C, flavonoids – FL e condensed tannins– TC (**quadrante II**I); ABTS – $ABTS^{\bullet+}$ (**quadrante IV**).**Em *scores***: samples of peel (C1, C2 e C3) and seeds (S1, S2 e S3).

In summary, the differences in the results of antioxidant activity may be linked to the type of extraction and the analysis system used in the bitter melon fruits. Even within the same variety, it depends on several factors, such as growth time, maturation, location, climate and soil conditions (Lopes et al., 2020).

4 CONCLUSION

The results of this study showed that the fruit has several nutrients, mainly protein (glutamic acid, proline and histidine), lipids (stearic, palmitic and oleic acid), minerals (potassium, iron and magnesium), fibers and phenolic compounds in the seeds and carbohydrates, vitamin C, carotenoids and flavonoids in the peel. Regarding antioxidant activity, the highest value obtained was with the FRAP test, indicating that the antioxidant compounds present in the fruit had better interaction with this method. In addition to volatile compounds, with high concentrations of linalool in the peel.

And from obtaining the flour from the peel and seeds of the melon of São-Caetano, its potential use in food technology and its application in the development of new products was observed. Thus, the ripe melon of São-Caetano can be considered a promising source of nutrients important for human health, as long as its production is expanded. Therefore, it deserves attention for future studies, such as protein digestibility and applications as a functional ingredient in the food industry.

Author Contributions

Kelly Lima Teixeira- main author: Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft, Visualization. **Andrea Alves Seixas Lima**: Formal analysis. **Rita de Cássia Moura da Cruz:** Writing - review. **Higor Henrique de Lima Costa:** Writing - editing**. Deborah Murowaniecki Otero:** Conceptualization, Supervision, Writing - review & editing.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the production of this article.

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6 CONSIDERAÇÕES FINAIS

Diante da análise dos resultados pode-se verificar que a técnica de secagem à frio (liofilização) da casca e sementes do melão de São-Caetano foi importante para preservação de aspectos físico-químicos como lipídios, proteínas e cor, além dos compostos bioativos e antioxidantes.

Os diferentes métodos de verificação de atividade antioxidante (FRAP, DPPH e ABTS), variou significativamente nos resultados encontrados, mesmo utilizando o mesmo processo de extração. O que pode ser explicado pela interação dos radicais com os componentes presentes no fruto, com isso o método FRAP foi que obteve maiores valores devido a afinidade com compostos existentes nas amostras como compostos fenólicos e taninos.

Foi observado uma grande diversidade de lipídios nas sementes, minerais e proteínas, com destaque para os aminoácidos ácido glutâmico, prolina e histidina. Dessa forma, ressalta-se a necessidade ampliação deste estudo com o fruto de *Momordica charantia*, com a finalidade de futuras aplicações desse fruto em alimentos, principalmente na forma de farinha, bem como análise sensorial desses produtos fortificados. Portanto, o melão de São-Caetano é uma Planta Alimentícia Não Convencional que pode contribuir com a indústria alimentícia e ajudar a combater a segurança alimentar e nutricional da população.

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PRODUÇÃO TÉCNICO-CIENTÍFICA

• Participação em Trabalho Completo (publicado em anais de eventos):

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• Participação em Resumo Expandido (publicado em anais de eventos):

TEIXEIRA, K. L.; LIMA, A. A. S.; CRUZ, R. C. M.; SANTOS, L. F. P.; OTERO, D. M.. Análise do teor proteico de frutos alimentícios não convencionais. In: III Semana de Engenharia de Alimentos da Universidade Federal de Uberlândia, 2023, Uberlândia. Anais da Terceira Semana da Engenharia de Alimentos da Universidade Federal de Uberlândia. Uberlândia: Sistemas de Biblioteca da UFU, 2023. v. 4. p. 161-165

• Participação em Resumo (publicado em anais de eventos):

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• Palestra/Curso Ministrado/Trabalho Apresentado:

1. CUNHA, Y. R. ; TEIXEIRA, KELLY LIMA. COMPOSIÇÃO FÍSICO-QUÍMICA E CENTESIMAL DO BIRIBIRI (AVERRHOA BILIMB L.) IN NATURA E APÓS FERMENTAÇÃO LÁTICA CONTROLADA PARA PRODUÇÃO DE PICLES PROBIÓTICO. 2024. (Apresentação de Trabalho/Congresso).

2. TEIXEIRA, KELLY LIMA; LIMA, A. A. S. ; CRUZ, R. C. M. ; MIRANDA, B. M. ; OTERO, D. M. . IDENTIFICAÇÃO E QUANTIFICAÇÃO DE COMPOSTOS VOLÁTEIS NA CASCA DO MELÃO-DE-SÃO-CAETANO. 2024. (Apresentação de Trabalho/Congresso).

3. TEIXEIRA, KELLY LIMA; LIMA, A. A. S.; CRUZ, R. C. M. ; OURO, L. ; VELOSO, L. ; FERREIRA-RIBEIRO, C. D. ; MATOS, L. C. P. ; OTERO, D. M. . ELABORAÇÃO E CARACTERIZAÇÃO FÍSICO-QUÍMICA DE MASSA TIPO NHOQUE À BASE DE INHAMINHO (Colocasia esculenta (L.) Schott). 2024. (Apresentação de Trabalho/Congresso).

4. LIMA, A. A. S.; TEIXEIRA, KELLY LIMA; SANTOS, L. F. P.; CRUZ, R. C. M.; OTERO, D. M. . COMPOSTOS BIOATIVOS DO CAMBUCI (Campomanesia phaea). 2024. (Apresentação de Trabalho/Congresso).

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6. GEANBASTIANE, B. A. ; ALMEIDA, M. S. ; ABREU, K. L. O. ; TEIXEIRA, K. L. ; MENEZES, R. V. . PLANTAS ALIMENTÍCIAS NÃO CONVENCIONAIS COMO ALTERNATIVA SUSTENTÁVEL PARA O DESENVOLVIMENTO DE NOVOS PRODUTOS. 2024. (Apresentação de Trabalho/Outra).

7. TEIXEIRA, K. L.; OTERO, D. M. Caracterização físico-química da polpa do melão-de-são-caetano (Momordica charantia). 2023. (Apresentação de Trabalho/Simpósio).

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- Participação (ouvinte) em Evento Internacional:

Workshop Internacional Sustentare e Wipis: Sustentabilidade, indicadores e Gestão de Recursos Hídricos. 2024.

- Participação (ouvinte) em Evento Nacional/Regional/Local:

29° Congresso Brasileiro de Ciência e Tecnologia de Alimentos. 2024.

15° SLACAN - Simpósio Latino Americano de Ciência de Alimentos e Nutrição: "A Revolução da Ciência de Alimentos e Nutrição: Alimentando o Mundo de Forma Sustentável". 2023.

2° Seminário de Ciência de Alimentos. 2023.

Avanços na tecnologia de secagem de produtos de origem vegetal. 2023.

Escrita científica: Busca e manejo de informação científica para produção de artigos científicos. Universidade Federal da Bahia, UFBA, Brasil.

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II Simpósio Integrado dos Programas de Pós-Graduação da Faculdade de Farmácia (SIPPFar). 2023.

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