Pillole di Opuntia

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AGGIUNTA DI FARINE DI OPUNTIA PER LA PRODUZIONE DI PASTA NUTRACEUTICA

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In questo terzo numero presentiamo una ricerca condotta in Brasile dove viene testato la polvere di Opuntia come aggiunta alla farina di grano per l'arricchimento nutritivo della pasta. La pasta secca è riconosciuta come uno degli alimenti di base consumati a livello globale per la sua versatilità, facilità di preparazione e conservazione, buona qualità nutrizionale e costo accessibile. Recentemente, diversi studi hanno esplorato iniziative per migliorare la qualità nutrizionale della pasta secca attraverso l'incorporazione parziale o la sostituzione completa dell'ingrediente base di grano con sottoprodotti dell'agroindustria o piante sottoutilizzate.

Il cactus fichidindia (Opuntia ficus-indica), noto anche come nopal, è stato identificato come una promettente fonte per arricchire la pasta secca. Questo cactus, originario del Messico ma coltivato in diverse regioni del mondo, è ricco di fitochimici come acidi fenolici, flavonoidi, acidi citrici e malici, oltre a contenere carboidrati in quantità limitata. La ricerca si è concentrata su innovative applicazioni dei cladodi di Opuntia ficus-indica nell'industria alimentare.

I cladodi di Opuntia ficus-indica possono diventare nuove risorse per fortificare gli alimenti di base, offrendo potenziali effetti nutraceutici, tra cui proprietà anticancro, antiossidanti, anti-infiammatorie, antidiabetiche (Tipo II) e contro l'iperlipidemia e l'ipercolesterolemia.

Studi scientifici indicano che lo sviluppo di prodotti come pane, biscotti e film bioattivi arricchiti con prodotti di Opuntia ficus-indica sta emergendo come una tendenza nell'industria alimentare. Pertanto, questo studio ha valutato diverse formulazioni per la preparazione di pasta tipo tagliatelle arricchita con farina di Opuntia.

Le conclusioni indicano che la preparazione di pasta arricchita con farina di Opuntia è stata un successo, producendo un prodotto finale ricco in composti fenolici, proteine e vitamina C. La formulazione con il 10% di farina di Opuntia è emersa come la più promettente, mantenendo un equilibrio accettabile di acidità e fornendo all'impasto attributi nutrizionali significativi.

TITOLO:

Sostituzione parziale della farina di frumento con farina di Opuntia. Preparazione della pasta

INTRODUZIONE:

Il processo di globalizzazione ha influenzato in modo significativo le abitudini alimentari della popolazione mondiale. La pasta secca è ampiamente riconosciuta come uno degli alimenti di base consumati in tutto il mondo, grazie alla sua versatilità, facilità di preparazione e conservazione, buona qualità nutrizionale e costi accessibili. Inoltre la pasta secca, in quanto prodotto economico e duraturo, costituisce un'ottima matrice per l'arricchimento nutrizionale, dato che la pasta di grano tradizionale è priva di alcuni nutrienti. Pertanto, studi recenti hanno evidenziato diverse iniziative volte a migliorare la qualità nutrizionale di questo prodotto. Un'alternativa molto promettente prevede l'incorporazione parziale o la sostituzione completa dell'ingrediente del grano con sottoprodotti dell'agroindustria o piante sottoutilizzate nella società, che tuttavia possiedono un alto valore nutritivo e possono contribuire al miglioramento della salute e del benessere della popolazione.

Il fico d'india (Opuntia ficus-indica), noto anche come cactus nopal, è probabilmente originario del Messico ma è coltivato in varie regioni del mondo per la sua eccellente adattabilità. La pianta appartiene alla famiglia delle Cactaceae ed è composta da quattro parti principali: i cladodi, i fiori, i frutti e i semi. I cladodi sono commestibili e tradizionalmente consumati come verdure fresche o cotte in Messico. Tuttavia, in alcuni paesi, come il Brasile, il loro utilizzo è più legato all'alimentazione animale e meno esplorato per il consumo umano.

Dato il potenziale tecnologico di questa pianta e la sua ricca composizione, che comprende sostanze fitochimiche come acidi fenolici e flavonoidi, acidi citrico e malico e piccole quantità di carboidrati, la composizione di questa pianta ha suscitato interesse nella ricerca attuale, che si è concentrata su soluzioni innovative applicazioni dei cladodi nell'industria alimentare.

Il concetto di utilizzo di sottoprodotti o piante sottoutilizzate ricche di composti bioattivi è in linea con la crescente domanda da parte dei consumatori di molecole naturali che hanno dimostrato di promuovere il benessere. Nello specifico, i cladodi di Opuntia ficus-indica nell'industria alimentare possono diventare nuove risorse per fortificare gli alimenti di base. I loro potenziali effetti nutraceutici includono possibili effetti antitumorali, proprietà antiossidanti, benefici antinfiammatori, effetti antidiabetici (tipo II), nonché anti-iperlipidemia e ipercolesterolemia. L'applicazione dei cladodi di Opuntia ficus-indica nei prodotti alimentari è ancora limitata ma emergente e del tutto fattibile.

Sulla base di studi scientifici presenti in letteratura, lo sviluppo di prodotti come pane, biscotti e film bioattivi arricchiti con prodotti a base di Opuntia ficus-indica dimostra questa tendenza verso la trasformazione degli alimenti convenzionali in alimenti funzionali, evidenziando il potenziale dei cactus per l'industria alimentare. Tuttavia, lo sviluppo di pasta arricchita utilizzando la farina di Opuntia ficus-indica non è stato esplorato. Alla luce di quanto sopra, questo studio ha mirato a valutare diverse formulazioni per la preparazione di pasta tipo tagliatelle per creare un prodotto arricchito con farina di Opuntia ficus-indica.

CONCLUSIONI:

La preparazione della pasta arricchita con farina di Opuntia ha avuto successo, ottenendo un prodotto finale che presenta una notevole ricchezza di composti fenolici, proteine e vitamina C, che svolge anche un ruolo cruciale nella stabilità del prodotto durante la conservazione. Tra le varie formulazioni testate, la pasta con il 10% di farina di palma si è rivelata la più promettente. Ciò è dovuto al suo rapporto equilibrato, che mantiene un livello accettabile di acidità e fornisce all'impasto attributi nutrizionali significativi. Vale la pena notare che all'aumentare della quantità di farina di palma, la rete del glutine viene influenzata, il che può essere attribuito ad una maggiore compattazione dei granuli di amido. Questi risultati indicano il potenziale della formulazione al 10% come opzione praticabile per la produzione di pasta fresca arricchita con quantità maggiori di composti benefici per il benessere dei consumatori, sottolineando l'importanza della ricerca continua nello sviluppo di opzioni alimentari più sane e saporite.

A SEGUIRE, LA RICERCA SCIENTIFICA COMPLETA

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Proprietà antitumorali e fitochimici dell'Opuntia ficus indica: tendenze attuali e prospettive future

Article

Partial Substitution of Wheat Flour with Palm Flour in Pasta Preparation

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Abstract: Pasta, a globally cherished staple food, is consumed on a wide scale. However, conventional wheat-based pasta often lacks nutrients that can be incorporated to add value to the new product. To address this nutritional deficiency and enhance the health benefits for consumers, a promising approach is to incorporate *Opuntia ficus-indica* flour as a partial substitute for wheat flour. The primary objective of this study was to craft enriched tagliatelle pasta using *Opuntia ficus-indica* flour. The evaluation encompassed an assessment of physical-chemical attributes, color quality, cooking properties, texture profile analysis (TPA), and the analysis of bioactive compounds within the pasta products. Upon conclusion of the experiments, the F10 formulation, comprising 10% *Opuntia ficus-indica* flour, emerged as the most favorable pasta option. It exhibited an acceptable acidity level of 3.71% and demonstrated remarkable nutritional characteristics. These findings suggest that this formulation could serve as a promising alternative for the production of health-conscious pasta.

Keywords: pasta; cooking properties; *Opuntia fícus-indica* (L.)

1. Introduction

The process of globalization has significantly influenced the dietary habits of the world population. Dry pasta is widely recognized as one of the food staples consumed worldwide, thanks to its versatility, ease of preparation and storage, good nutritional quality, and affordable cost [1]. Furthermore, dry pasta, as an affordable and long-lasting product, serves as an excellent matrix for nutritional enrichment, given that traditional wheat pasta lacks certain nutrients [2]. Therefore, recent studies have shown various initiatives aimed at enhancing the nutritional quality of this product [1–4]. A highly promising alternative involves the partial incorporation or complete substitution of the wheat ingredient with agroindustry byproducts or underutilized plants in society, which, nonetheless, possess high nutritional value and can contribute to the improvement of the health and well-being of the population.

The prickly pear cactus (*Opuntia ficus-indica*), also known as the nopal cactus, likely originated in Mexico but is cultivated in various regions around the world due to its excellent adaptability [5]. The plant belongs to the *Cactaceae* family and consists of four main parts: the cladodes, flowers, fruit, and seeds. Cladodes are edible and traditionally consumed as fresh or cooked vegetables in Mexico. However, in some countries, like Brazil, their use is more related to animal feed and less explored for human consumption. Given the technological potential of this plant and its rich composition, which includes phytochemicals such as phenolic acids and flavonoids, citric and malic acids, and small

amounts of carbohydrates [6], the composition of this plant has sparked interest in current research, which has focused on innovative applications of cladodes in the food industry.

The concept of utilizing byproducts or underutilized plants rich in bioactive compounds aligns with the growing consumer demand for natural molecules that are proven to promote well-being [7]. Specifically, the cladodes of *Opuntia ficus-indica* in the food industry can become new resources for fortifying staple foods. Their potential nutraceutical effects include possible anticancer effects, antioxidant properties, anti-inflammatory benefits, antidiabetic (Type II) effects, as well as anti-hyperlipidemia and hypercholesterolemia [8]. The application of *Opuntia ficus-indica* cladodes in food products is still limited but emerging and entirely feasible.

Based on scientific studies found in the literature, the development of products such as bread [9], cookies [10], and bioactive films [6] enriched with Opuntia ficus-indica products demonstrates this trend toward transforming conventional foods into functional foods, highlighting the potential of cacti for the food industry. However, the development of enriched pasta using *Opuntia ficus-indica* flour has not been explored. In light of the above, this study aimed to evaluate different formulations for the preparation of tagliatelle-type pasta to create a product enriched with *Opuntia ficus-indica* flour.

2. Materials and Methods

2.1. Material

For the preparation of the pasta, white wheat flour, chicken eggs, and *Opuntia ficus-indica* flour (palm flour) were used. The wheat flour, eggs, and cladodes for obtaining the palm flour were sourced from Solânea, Paraíba, Brazil. To produce the palm flour, the cladodes were sanitized and then sliced to a thickness of 2 mm. Excess water was drained, and the slices were subjected to the drying process in an oven with circulation at a temperature of 65 °C for 10 h. After drying, the dried cladode slices were ground. Table 1 summarizes the proximate composition of the edible parts of the ingredients used in pasta production.

Table 1. Proximate composition of the edible parts of the ingredients used in pasta production.

Components	* Wheat Flour (%)	* Chicken Egg (%)	** Palm Flour (%)
Moisture (%)	13.0	75.6	16.9
Carbohydrates (%)	75.1	1.6	60.6
Protein (%)	9.8	13.0	6.0
Lipids (%)	1.4	8.9	1.2
Dietary fiber (%)	2.3	na	nq
Ash (%)	0.8	0.8	16.4

nq: not quantified. na: not applicable. * Source: TACO—Tabela brasileira de composição de alimentos [11]. ** Experimental data from palm flour obtained by drying at 65 °C.

2.2. Experimental Design and Preparation of the Pasta

The experiment was carried out at the Bakery Laboratory of the Federal University of Paraíba, Campus-III, which is located in the city of Bananeiras-PB. As palm flour also contains hydrocolloids, which are hydrophilic molecules with varying structures, the presence of palm flour in the pasta formulation is expected to impact gluten development [12]. Therefore, based on available studies in the literature that have evaluated the partial substitution of wheat flour with other components [13,14], different levels of palm flour were selected to be added to the product. A completely randomized design was used, with four treatments/formulations and four repetitions of 50 g: F0 (control)—with no addition of palm flour; F5—formulation with 5% palm flour; F10—formulation with 10% palm flour; and F15—formulation with 15% added palm flour, as seen in Table 2.

Table 2. Formulations of prepared pasta.

Formulation	Wheat Flour (%)	Palm Flour (%)	Egg * (%)
F0	100	0	50
F5	95	5	50
F10	90	10	50
F15	85	15	50

* The proportion of egg was added in relation to the total amount of flour (wheat plus palm).

The preparation of the dough followed the method described by Kolarič et al. [13], with adaptations. Initially, the ingredients were carefully weighed on a semi-analytical balance to ensure the required precision according to the proposed formulations. After weighing, wheat flour and palm flour were thoroughly mixed until satisfactory homogeneity was achieved. Then, the wet ingredients, in this case, the eggs, were added. The dough was manually mixed until it reached the necessary point for kneading and gluten development. This kneading process was performed manually for 30 min, imparting resistance and elasticity to the dough. The subsequent rolling process was carried out using a specialized rolling pin designed for this purpose, allowing for standardized dough thickness. Shaping the dough to characterize it as a tagliatelle-type pasta, was conducted using a pasta machine of the Astro Mix brand, manufactured by Astromix Comercio Online Eireli. The resulting pasta was dried at 25 °C for 24 h. The pasta was then sealed in airtight plastic bags and stored at room temperature (25 ± 2 °C) until it was subjected to the necessary analyses. The pasta was prepared without the addition of salt.

2.3. Cooking Time, Cooking Yield, Cooking Loss, and Texture Profile

Cooking time (OCT) was determined by immersing 5 g of raw pasta in 250 mL of boiling water. Every 30 s a sample was collected to verify the absence of the white nucleus in the center of the pasta. After the white crumb disappeared, the cooking time was recorded. This analysis was performed in triplicate. To determine the cooking yield (%), the method described by Zhu et al. [15]. Five grams (5 g) of raw pasta was immersed in 500 mL of boiling water for 5 min. Then, the cooked pasta was removed from the hot water and washed with 100 mL of cold distilled water to stop cooking. The pasta was placed on filter paper to drain excess water. The dough remained at rest for 3 min and the weight was subsequently recorded. Yields were calculated according to Equation (1):

$$CY = \frac{Fw - Iw}{Iw} \times 100 \tag{1}$$

where CY = Cooking yield; Fw = Final weight of the product; Iw = Initial weight of the product.

For the analysis of mass loss due to cooking, the remaining cooking water remained under heating for evaporation until approximately 20 mL remained. Then, the container with the remaining water was dried in an oven at 110 °C until it reached a constant weight. Cooking loss (%) was calculated using Equation (2):

$$LC = \frac{Wcp - Cw}{Wrp - Mrp} \times 100 \tag{2}$$

where LC = loss by cooking; Wcp = weight of cooked pasta; Cw = container weight; Wrp = weight of raw pasta; Mrp = moisture content of raw pasta.

The texture profile analysis was performed using a texturometer of the brandable Micro System model TAXT plus Texture Analyser. For the test, five strands of pasta were placed in the center of the platform side by side. Hardness (which is the initial peak of force), adhesiveness, and chewability were evaluated. For that, a PROBE 1″ ALUMINIO P/1 was used, pre-test speed 0.5 m/s, test 1 m/s, and post-test 1 m/s. Strain 75% with an automatic trigger, according to the methodology adapted from Zhu et al. [15].

2.4. Physical-Chemical Quality

Moisture, ash, total acidity, pH, starch content, and protein content of the pasta formulations were determined using the methodology of the Adolf Lutz Institute [16]. Moisture content (%) was determined by drying the sample in an oven at 105 °C for 24 h. The total ash (%) was determined by incinerating the sample in a muffle at a temperature of 550 °C until the ash reached a white or slightly grayish color.

The titratable acidity was determined by the titrimetric method using 1g of the sample, to which 50.0 mL of distilled water and 3 drops of 1% alcoholic phenolphthalein were added, using 0.1 N sodium hydroxide (NaOH) solution, standardized with potassium biphthalate. The pH was determined using the mPA-210 pH meter from Tecnopon.

The starch content was determined using the Lane-Eynon Method and the Fehling Reagent. The Lane-Eynon Method is based on the reduction of a known volume of alkaline copper reagent (Fehling) to cuprous oxide. The endpoint is indicated by methylene blue, which is reduced to its leuco form by a small excess of reducing sugar.

Protein content (g/100 g) was determined by the Micro-Khejdahl method, with a conversion factor of 6.25 [17]. The Micro-Kjeldahl protein determination method is based on the acid digestion of the sample, followed by the distillation and titration of the released ammonia. Lipids (g/100 g) were determined using the method by Folch et al. [18], using polar solvents, methanol, and chloroform.

2.5. Colorimetric Analysis, Pigments, and Bioactive Compounds

The color of the products was determined using a Chroma Meter model DH-WF-30 colorimeter, with analyses being carried out in triplicate for each sample. For color measurement, cooked pasta was placed on a white, flat surface to ensure accurate color reading.

2.6. Pigments and Bioactive Compounds

Chlorophyll a and b contents were determined according to the Nagata and Yamashita method [19]. The extraction was performed with acetone/hexane (4:6 *v/v*) at once, and the optical density of the supernatant was measured by a spectrophotometer at wavelengths of 663 nm and 645 nm, and calculated according to Equations (3) and (4), respectively. From these values, the content of chlorophyll a and b are determined in mg/100 g.

$$Ca = [(12.21\, Abs.\,663 - 2.81\, Abs.\,645)\,/massa\,(g)] \times 100\,/1000 \tag{3}$$

$$Cb = [(20.13\, Abs.\,645 - 5.03\, Abs.\,663)\,/massa\,(g)] \times 100\,/1000 \tag{4}$$

Abs. = absorbance

To determine the total phenolic compounds, 0.1 to 0.5 g of the sample was weighed in a Falcon tube covered with aluminum foil, then this amount of sample was transferred to 50 mL of distilled water to prepare an aqueous extract. After 24 h, an aliquot of 500 μL of the pasta extract was removed, then the Folin Ciocalteau reagent was added and homogenized in a vortex tube shaker. The sample was allowed to rest for 5 min. After the reaction time, 20% sodium carbonate was added, followed by stirring again and resting in a water bath at 40 °C for 30 min. After the reaction time, the sample was allowed to cool, and in a dark environment, the samples were transferred to the cuvettes, and the reading was performed in a spectrophotometer at 765 nm, using the White solution to zero the spectrophotometer [20].

The vitamin C content was calculated by titration, using 5 mL/g of the sample plus 45 mL of 0.5% oxalic acid, and titered with Tillman's solution until it reached a pink color [16].

2.7. Morphology of Particles

Particle morphology was obtained by scanning electron microscopy (SEM). Samples were sprayed with gold and observed under 1000× magnification at 10 kV with an SEM (Zeiss Sigma300, Carl Zeiss AG, Oberkochen, Baden-Wuberg, Germany).

2.8. Statistical Analysis

Data were subjected to analysis of variance and means were compared using Tukey's test at a 5% probability level.

3. Results and Discussions

3.1. Cooking Properties and Texture Profile

The optimal cooking time (OCT), the Loss by Cooking (LC), and the cooking yield (CY) were analyzed (Table 3). There was an influence of the addition of palm flour ($p < 0.05$) in all tests performed on cooking properties. The OCT increased with the addition of palm flour. The CY decreased with the addition of palm flour only for the control, where treatments F5 and F15 were the same and the LC increased with the addition of palm flour. These behaviors have been observed with other types of pasta where vegetable flour is added, as is the case of studies by Zhu et al. [15], which worked with the addition of flaxseed flour in fresh pasta.

Table 3. Cooking properties and texture profile of pasta with partial replacement of wheat flour by palm flour.

Variables	F0	F5	F10	F15
* OCT (s)	317 ± 14 [d]	373 ± 6 [c]	435 ± 4 [b]	493 ± 10 [a]
* CY (%)	66.7 ± 3.5 [a]	51.8 ± 1.9 [b]	44.5 ± 1.8 [c]	51.8 ± 2.6 [b]
* LC (%)	3.3 ± 0.4 [c]	4.0 ± 0.3 [b]	7.6 ± 1.5 [a]	9.1 ± 0.5 [a]
Hardness (kg)	5.22 ± 0.16 [c]	6.29 ± 0.06 [b]	6.80 ± 0.02 [b]	8.39 ± 0.23 [a]
Adhesiveness (kg s)	−0.60 ± 0.14 [a]	−0.24 ± 0.03 [b]	−0.30 ± 0.02 [b]	−0.18 ± 0.01 [b]
Chewability (kg)	3.89 ± 0.08 [c]	5.81 ± 0.23 [b]	5.51 ± 0.33 [b]	7.75 ± 0.18 [a]

Means followed by the same letter (a–d) in the columns, do not differ according to Tukey's test at 5% probability. * OCT is the optimal cooking time, CY is the cooking yield, and LC is the loss by cooking.

Li et al. [21], in a study of fresh pasta with the addition of powdered Ginkgo biloba, found similar behavior to palm pasta. The authors explain that vegetable powder can prevent the absorption of water by the starch molecules, making the cooking process more difficult [21].

The cooking yield decreased with the addition of palm flour ($p < 0.05$), attesting that the cooking yield of fresh pasta is also reduced as the concentration of flaxseed flour increases. This fact may be due to the presence of vegetable powder interfering with the relationship between water and starch, making it difficult to gelatinize [15].

The loss from cooking the pasta also increased with the addition of palm flour ($p < 0.05$). The loss during the cooking process occurs due to the breakdown of the compact composition of the dough and the removal of soluble substances. In their works, Li et al. [21] also observed this behavior, explaining that it may be due to the release of soluble compounds from the added flours. However, the range of values found for palm flour was greater than for flaxseed flour [15] and Ginkgo Biloba flour [21]. The increase in mass loss during cooking due to the addition of palm flour can be explained by the formation of a less efficient gluten network for retaining starch polymers [2]. Although it is known that the addition of hydrocolloids and the use of proteins such as egg result in improved pasta quality [22], in the present study, we observed that despite the presence of hydrocolloids in palm flour and the addition of egg to the formulation, cooking loss increased with the increasing concentration of palm flour. Nevertheless, the values observed in Table 3 indicate that only pasta with 15% palm flour exhibited a cooking loss greater than 8%. According to Baah et al. [23], an acceptable cooking loss for desirable pasta of good quality

should be less than or equal to 8%. Therefore, the formulations developed in this study are acceptable, except for the formulation with 15% palm flour.

About the texture profile, it is observed that the hardness underwent a significant change ($p < 0.05$), having been increased by the addition of palm flour. This fact was also found in studies by Li et al. [21], where the ginkgo biloba flour increased the hardness of the pasta produced. The increase in pasta hardness when adding palm flour may be related to the difference in water absorption capacity between the two flours used in the formulation, which can affect dough hydration and, in turn, the hardness of the cooked pasta. Hardness is a texture indicator related to the force required to bite into the pasta and directly influences consumers' purchasing inclination [24].

Adhesiveness is the negative area of the curve, representing the time it takes the probe to detach from the sample [25]. Pasta added with palm flour suffered a significant increase ($p < 0.05$) in adhesiveness. Previous studies show that this behavior is common when adding vegetable flour to fresh pasta [15,21,26].

Adhesiveness is associated with the degree of starch dissolution and also with its incorporation into the pasta surface. Due to this, the addition of vegetable flour reduces the amount of starch, reducing viscosity and adhesiveness [21].

Chewability is understood as the force required to grind food [21]. This parameter also increased ($p < 0.05$) with the addition of palm flour. The chewability data tend to corroborate the hardness data found, and since chewability is the necessary force for crushing, it is natural that hardness also increases. This behavior of increased chewability has been reported in previous studies [15,21,26].

This increase in chewability values may be due to the presence of palm flour. Palm flour has a good amount of fiber and sugars, and this composition can increase pasta's protein-polysaccharide system [27].

3.2. Physical-Chemical Quality

Table 4 shows the values obtained for the physical-chemical profile of pasta with partial substitution of wheat flour for palm flour.

Table 4. Physical-chemical profile of pasta with partial substitution of wheat flour by palm flour.

Variables	F0	F5	F10	F15
Moisture (%)	38.4 ± 1.1 [c]	35.4 ± 0.3 [d]	40.1 ± 0.3 [b]	42.9 ± 0.5 [a]
Ash (%)	1.05 ± 0.05 [d]	1.67 ± 0.08 [c]	2.28 ± 0.04 [b]	3.05 ± 0.02 [a]
Total acidity (%)	1.96 ± 0.02 [c]	3.14 ± 0.04 [b]	3.71 ± 0.01 [b]	6.41 ± 0.03 [a]
pH	5.97 ± 0.02 [a]	5.43 ± 0.03 [b]	5.23 ± 0.01 [c]	5.01 ± 0.03 [d]
Starch (g/100 g)	41.0 ± 2.4 [a]	32.6 ± 1.7 [b]	25.6 ± 0.8 [c]	22.6 ± 1.5 [c]
Proteins (g/100 g)	12.28 ± 0.10 [b]	11.95 ± 0.10 [b]	12.90 ± 0.12 [a]	14.00 ± 0.06 [a]
Lipids (g/100 g)	5.22 ± 0.24 [a]	5.68 ± 0.01 [a]	5.83 ± 0.15 [a]	5.34 ± 0.49 [a]

Means followed by the same letter (a–d) in the columns, do not differ according to Tukey's test at 5% probability.

The moisture contents presented changed significantly ($p < 0.05$). The addition of palm flour to the formulation increased moisture values, in line with the increase in palm flour concentration, except for the formulation with 5% palm flour, which showed atypical behavior and may have occurred due to a possible variation in the thickness of the pasta. According to the international standard (Codex Alimentarius [28]), which includes guidelines for the production of fresh pasta, it should not exceed the maximum limit of 35%. In the present study, a higher humidity than the standard was noted, especially for pasta produced with higher concentrations of palm flour. Due to the presence of hydrocolloids in palm flour, these components may explain the greater water retention in the product. This problem can be solved by optimizing the lamination process, where the production of thinner threads can facilitate the drying of the pasta.

The total moisture content affects the water activity, water retention, and other components present in the pasta, in addition to influencing the appearance, internal structure, and

texture [29]. The use of flour from vegetable sources did not change the moisture content in the added pasta of such products, as demonstrated in studies by Wang et al. [29] and Zhu et al. [15], testing formulations of corn flour and flaxseed, respectively, not agreeing with the data found in the present work. However, Uthaiand Chetyakamin [26] attested that the addition of tamarind seed flour increases the moisture of the pasta, which is consistent with the data of this work. The behavior of the pasta studied may have been influenced by the hygroscopic characteristic of palm flour because due to the amount of sugar, a small amount of moisture may be reabsorbed [27].

The ash content of pasta underwent a significant increase ($p < 0.05$) with the addition of the flour. Previous studies have shown that dry palm has high levels of iron, zinc, calcium, potassium, and magnesium [27,30].

This increase in ash content was also verified by Uthai and Chetyakamin [26] in the study with the addition of tamarind seed flour. However, the range of values described here is greater than those indicated by the authors. This is due to the high mineral content of palm flour, as previously demonstrated. This increase in mineral content can be a viable alternative for dietary changes, in which it is necessary to add some of the constituents found in flour, to this pasta.

Regarding the titratable acidity, the tested formulations showed differences among themselves ($p < 0.05$). With the increase in sprout flour concentrations, there was a significant increase in acidity, as previously mentioned. This fact can be explained by the presence of malic acid in the flour. This increase in acidity corroborates with the decrease in the pH of the pasta.

Acidity results similar to fresh pasta formulations have been described by Xiong et al. [31]. Close values (3.9–6.1%) were also found by Uthai and Chetyakamin [26]. However, the control treatment without the addition of tamarind seed flour at the end of the experiment ended up with 3.9% higher acidity than that observed in these experiments. These studies point out that the addition of flour from vegetable sources tends to increase the acidity of the pasta due to the presence of organic acids such as malic, citric, and ascorbic. This can give these pastas more longevity because of the presence of bacteria, but cause a slightly acidic taste [26,31].

The addition of palm flour directly influenced the pH values of the prepared pasta ($p > 0.05$). As the sprout flour concentration increased, there was a noticeable decrease in pH, resulting in a more acidic pasta. This phenomenon can be attributed to the presence of malic acid in the sprouts, which probably gave this acidity to the pasta [32].

This fluctuation in pH levels aligns with results from previous studies involving pasta formulations enriched with other ingredients, such as flaxseed and rice [15,33,34]. According to Li [32], certain organic acids, including malic acid, have been used in pasta production to improve the stability of the fresh product during storage since the acidic product hinders the development of spoilage microorganisms.

The starch content reduced significantly ($p < 0.05$) with the addition of palm flour, having been effective up to the content of 10% of palm flour, where the reduction occurred around 28%. This product can be characterized as a light product since there was a reduction of over 25% in the content of this carbohydrate. This reduction in the amount of starch was also reported by Thangthanantorn et al. [35], in the study with fresh pasta added with banana flour, and by Silva, Brunques, and Gurak [36] in fresh pasta with added alfalfa sprout flour.

The importance of determining starch in pasta is because this sugar influences the viscosity, stability, cooking properties, texture, rheology, structure, and sensory attributes of this product [37]. The reduction of the starch content can result in fresh pasta with fewer calories and more sugars from palm flour, considered more advantageous for human consumption compared to starch that contains a high glycemic index, and this product may become viable for consumption.

The protein content had its values positively affected by the addition of palm flour to the 10% formulation ($p < 0.05$). The palm bud flour, after drying in an oven at a temperature

of 65 °C, presented an amount of 6 g/100 g of proteins. This may explain the significant increase in the amount of protein in prepared pasta. It is worth mentioning that the tested concentrations did not negatively interfere with the formation of gluten, considering that there was no difficulty in forming the pasta aspect of these formulations.

Similar to the data found in the present work, the protein content of fresh pasta, without enrichment, in studies by other authors shows values between 5 and 15 g/100 g of proteins. For formulations that contain flour from vegetable sources, this value varies from 7 to 15 g/100 g [26,31,38]. According to Li et al. [39], the total protein content of raw and cooked fresh pasta ranges from 12 to 13 g/100 g. Most of this amount is represented by the gluten proteins that form from the kneading of the dough, together with the sets of egg proteins: albumin, glutenin, and gliadin.

Regarding the amount of lipids, the addition of palm flour did not affect the amount of fat in fresh pasta (Table 3). It is noted that the lipid content found in the formulations is higher compared to conventional pasta. These levels can be explained by the addition of the whole egg to the production of pasta. The amount of fat is an important factor to study the quality of pasta, both fresh and cooked. Lipids can easily deteriorate in the presence of light and oxygen, releasing glycerol and causing a rancid taste; oxidative rancidity releases peroxyl radicals [31].

3.3. Colorimetric Analysis, Pigments, and Bioactive Compounds

The parameters L*, a*, and b* were analyzed in accordance with the CIElab system (Table 5), having been detected after variance analysis influenced the studied parameters ($p < 0.05$). This parameter is considered extremely important in the pasta industry, as the color of the pasta is one of the parameters that measure consumer acceptability [40].

Table 5. Color, pigments, and bioactive compounds parameters of pasta with partial replacement of wheat flour by palm flour.

Variables	F0	F5	F10	F15
L*	61.66 ± 0.31 [a]	53.18 ± 0.85 [c]	54.97 ± 1.55 [bc]	56.18 ± 0.94 [b]
a*	4.62 ± 0.09 [a]	1.75 ± 0.37 [b]	1.54 ± 0.03 [b]	0.59 ± 0.05 [c]
b*	21.37 ± 1.73 [a]	16.38 ± 0.60 [b]	12.72 ± 0.68 [c]	8.44 ± 0.37 [d]
Chlorophyll a (mg/100 g)	0.00 ± 0.00 [c]	0.12 ± 0.03 [b]	0.25 ± 0.03 [a]	0.34 ± 0.07 [a]
Chlorophyll b (mg/100 g)	0.00 ± 0.00	0.02 ± 0.02 [b]	0.04 ± 0.01 [a]	0.02 ± 0.01 [a]
Vitamin C (mg/100 g)	7.2 ± 0.7 [c]	25.1 ± 2.7 [b]	29.5 ± 1.9 [ab]	33.0 ± 1.8 [a]
Phenolics (mg of Gallic acid/100 g)	5.5 ± 5.6 [c]	71.6 ± 5.3 [c]	116.6 ± 10.3 [b]	152.0 ± 14.3 [a]

Means followed by the same letter (a–d) in the columns, do not differ according to Tukey's test at 5% probability.

The pigments found in palm flour likely have an impact on the luminosity values (L*). As summarized in Table 5, the incorporation of palm flour resulted in a decrease in the luminosity of the end product, imparting a darker hue compared to conventional pasta. This observation was further substantiated through visual inspection of the product's color, as can be seen in Figure 1.

This phenomenon is consistent with findings from other studies that incorporate flour derived from plant-based sources into pasta, such as the research conducted by Duan et al. [40], who explored the addition of flaxseed flour to fresh pasta. Bao et al. [41] also detected this behavior with the addition of potato flour to fresh pasta. Possibly, this decrease in luminosity is due to the presence of vegetable pigments, in addition to the action of enzymes such as polyphenol oxidase that darken some flours [41].
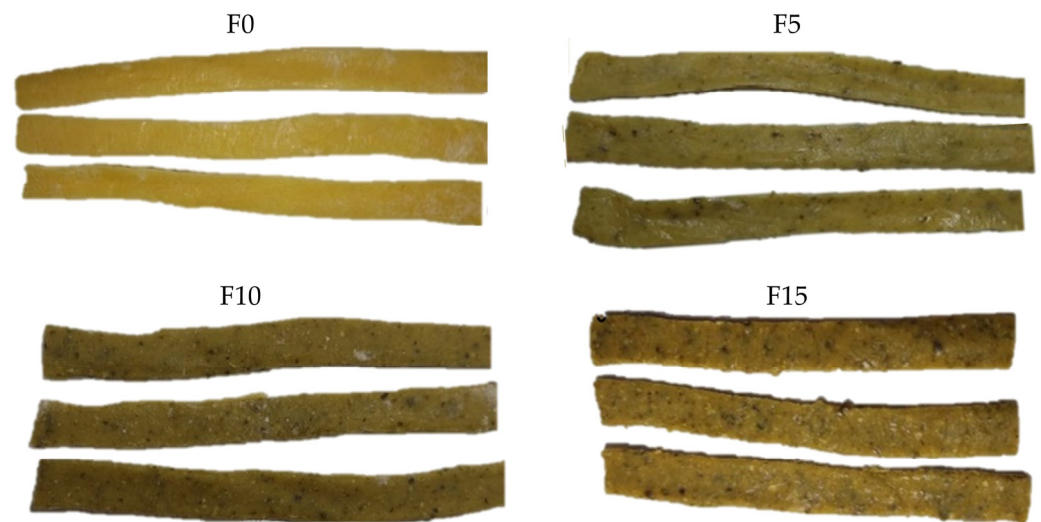
Figure 1. Picture of the produced pasta. Images F0, F5, F10, and F15 correspond to the formulations with the addition of 0%, 5%, 10%, and 15% palm flour, respectively.

The color coordinate a* (Table 5) represents the green-red band. The smaller the value of a* the greener the product is; in contrast, the higher the value of a* the redder the product must be [41]. There was a reduction ($p < 0.05$) in the values of a* showing that the more flour was added, the greener the product became, and this fact can be explained by the presence of palm pigments such as chlorophyll, which gives a green color [26].

The decrease in the value of a* was also identified by Liu, Meenu, and Xu [42] using unripe banana flour in the production of fresh pasta; the values found ranged from 1.12 to 0.52, ranging from 5 to 15% of unripe banana flour. These data corroborate those found in the present study.

Uthai and Chetyakamin [26] found consistent results, since the addition of tamarind seed flour significantly altered the values of a*, increasing the values of this parameter, possibly due to the presence of tamarind seed pigments.

The color coordinates b*, representing the yellow-blue spectrum, were significantly influenced ($p < 0.05$) by the addition of palm flour. A decrease in the values was observed, indicating a reduction in the pasta's yellowish hue, which might lead to consumer unease.

The addition of vegetable flour significantly affects the values of b*. However, the behavior varies according to the vegetable used. In the use of tamarind seeds, it was verified that the value of b* decreased with each increase in flour [26]. In the case of flaxseed flour, there was an increase in these coordinates [40]. In the case of sweet potato flour, the values of b* also increased. These studies prove that the addition of vegetable flour alters the color parameters. This may be due to the presence of plant pigments.

The greenish color of the pasta is probably due to the presence of chlorophyll, which gives the vegetables a green color. The addition of palm flour positively increased ($p < 0.05$) the a and b chlorophyll content of pasta.

The addition of palm flour increased the vitamin C content ($p < 0.05$) of the pasta. This fact is explained by the amount of ascorbic acid present in palm flour (53.41 mg/100 g) for dry flour at 65 °C. Other works with pasta added with flour or vegetable powders prove that the pasta manages to acquire good levels of vitamin C, as in the case of pasta with tamarind seed flour [26] and flaxseed flour [15]. The increase in vitamin C in pasta formulations with the addition of palm flour can enhance the characteristics of the dough, smoothing the wheat flavor, and making the final product more palatable. Furthermore, the addition of vitamin C to pasta can increase the viscoelasticity of the flour, especially in those with low gluten content [43]. Vitamin C is also a natural antioxidant that can help preserve the color of the pasta during storage. This is important because exposure to oxygen can lead to the darkening or aging of the pasta, affecting its flavor and appearance.

The content of phenolic compounds increased proportionally to the increase in palm flour in the pasta formulation. These values are explained by the high content of phenolic compounds found in palm flour (1452 mg/100 g).

This behavior of increasing the content of phenolic compounds in fresh pasta added with vegetable flour was also measured by Uthai and Chetyakamin [26]. Such behavior can result in palm flour being a good additive in the enrichment of fresh pasta. In addition to having antioxidant, anticancer, anti-inflammatory, and vasodilator effects, phenolic compounds are associated with the prevention of various diseases [44].

Kayama et al. [44] found that the addition of green tea powder significantly increased the values of phenolic compounds in fresh pasta. This behavior corroborates the data found in the present work. The control (without the addition of green tea powder) showed 59.56 mg of gallic acid/100 g, a value close to that found in this work. Padalino et al. [45], in a study with *Salicornia europaea* flour, a green plant, also found this significant increase in the content of phenolic compounds. Even with additions ranging from 5 to 20%, the increase in the content of phenolic compounds in the products studied is remarkable, both in this work and in works found in the literature.

3.4. Morphology of Particles

The microscopy results (Figure 2) at 1000× show that the starch granules were affected by palm flour. However, it is possible to note that the interaction did not prevent the formation of gluten.
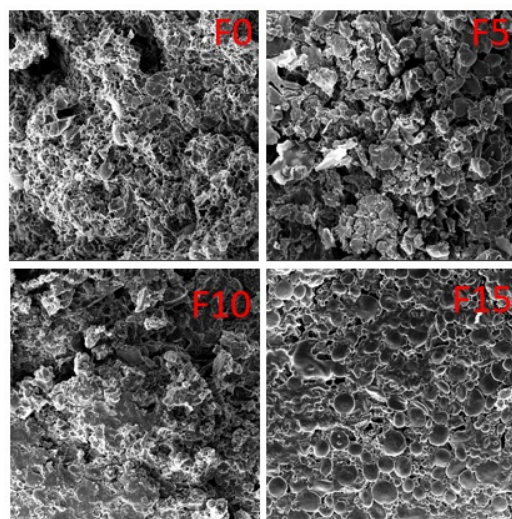

Figure 2. 1000× SEM photographs of pasta with partial replacement of wheat flour by palm flour. Images F0, F5, F10, and F15 correspond to the formulations with the addition of 0%, 5%, 10%, and 15% palm flour, respectively.

Palm flour interferes with starch retrogradation, affecting the attempt to reorganize water molecules, and impacting the formation of characteristic hydrogen bonds. As seen in the figures, as the concentration of palm flour increases, the granules are compelled to stick together, which explains the greater hardness of the pasta at higher concentrations of flour; this behavior was also noticed by Liu et al. [42] and also by Zhang et al. [25] in their work with Japanese walnut and fresh pasta formulations, respectively.

4. Conclusions

The preparation of pasta enriched with palm flour was successful, resulting in a final product that exhibits a remarkable richness in phenolic compounds, protein, and vitamin C, which also plays a crucial role in product stability during storage. Among the various formulations tested, pasta with 10% palm flour stood out as the most promising. This was due to its balanced ratio, maintaining an acceptable level of acidity and providing

the dough with significant nutritional attributes. It is worth noting that as the quantity of palm flour increases, the gluten network is impacted, which can be attributed to increased starch granule compaction. These findings indicate the potential of the 10% formulation as a viable option for the production of fresh pasta enriched with higher amounts of beneficial compounds for consumer well-being, underscoring the importance of ongoing research in the development of healthier and more flavorful food options.

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