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Research Article

Physical Characterization of *Erythrina edulis* (*chachafruto*) Fruits and Nutritional Composition of Derived by-Products

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Abstract

Erythrina edulis is a leguminous tree (Fabaceae) found mainly in western Venezuela. Its use has been directed to supplement the diet of ruminants, horses, and pigs, among other grazing animals. However, in recent years its potential nutritional properties have favored its use in human nutrition, finding a diversity of options in which it can be consumed. This paper uses official analysis and research methodologies to show the physical characterization of Venezuelan chachafruto pods and grains. Likewise, its potential to convert it into flour and protein isolate, evaluating their nutritional properties.

Keywords: *Erythrina edulis*; Chachafruto; Aminoacids; Legume Flour; Protein Meal; Protein Digestibility

Introduction

Erythrina edulis, also called chachafruto, pajuro, balú, bean mompás, nopas, bucaré, baluy, chaparuto and sachafruto, is a legume of the Fabaceae family native to the sub-Andean region of Latin America. In Venezuela, it is widely distributed in the state of Merida. This region meets the altitude and humidity requirements. This legume requires to develop [1]. Today, chachafruto plantations are also found in towns such as Colonia Tovar (Aragua state) and Galipan (La Guaira state). This legume is nutritionally high content of protein (18-22%) and carbohydrates (70-80%) (high caloric value), a beneficial aspect for communities that have limited access to animal protein sources and that also require ingesting a high daily calorie content. Colombia, Bolivia, and Peru have conducted extensive studies of this legume, associating it with food security and forming part of the standard diet of some communities in these countries. In Venezuela, studies on Erythrina edulis are just beginning; The use of flour from its grains has been promoted as a complement to other flours to develop products with more excellent nutritional value, such as the combination of chachafruto flour with corn flour to produce arepas for human consumption [2]. Also, it has been used as food for some species, such as the rainbow trout found in the Merida state [3]. The protein and carbohydrate content of Erythrina edulis can be used as a raw material to make other products from its macronutrients, extracting its starch and proteins separately to innovate functional products, increasing the added value as has been done with other legumes like soy. E. edulis has abundant amino acids [4], threonine, alanine, and phenylalanine; valine, proline, aspartic acid, lysine, and histidine in moderate amounts; the low amount of tyrosine, tryptophan, and traces of methionine. This protein is better quality than beans, lentils, peas, and beans and is comparable to eggs. The protein efficiency percentage of chachafruto is 1.15 higher than that of beans (0.88) and lentils (0.91). The biological value of the protein of chachafruto is 70.9, higher than that of lentils (44.6), beans (58), peas (63.7), and broad beans (54.8). E. edulis is a supplement option to enrich the nutritional value of foods with low protein content. Its correct combination with other vegetable protein sources can achieve a complete balance of amino acids required daily, which is why it can be considered a source for the extraction of its proteins to obtain flours, concentrates, or protein isolates, which favors an increase in its digestibility, considering that anti-nutritional factors. As saponins, trypsin inhibitors, lectins, and polyphenols should not remain after extraction or at least would be minimized. This research aimed to study the physical characteristics of the chachafruto grains, their potential in obtaining native flour, and the best extraction conditions for the protein isolation of chachafruto flour with its consequent characterization of the amino acid content and in vitro digestibility.

Materials and Methods

Harvested samples

The harvested *Erythrina edulis* (chachafruto) trees were chosen according to a completely randomized statistical model. Among the variables considered for selecting the trees were: fruits or pods in a state of physiological maturity, the height of the pods to be harvested on the tree, and the length of the pods. The chosen plantation was located at Latitude: 8.66839 (8° 40' 6.21" N). Longitude: -71.45638 (71° 27' 22.98" W) (Population of La Azulita, Merida state, Venezuela.

Characterization of the pods and fruits of *Erythrina edulis*

The weight, width, length, and thickness of the chachafruto pods were recorded. Then, the measurements above were made for the grains, and with them were determined geometric mean diameter, sphericity, and surface area [5]. It was estimated the yield of chachafruto grains.

Obtaining native flours and protein flours

Native flour was obtained following the methodologies [6] of other researchers, applying modifications from the laboratory of the research institute. Then, the extraction and precipitation of protein were made [7]. Figure 1 shows the work scheme.

Chemical composition and physicochemical analysis

The moisture content (925.10), total ash (923.03), total nitrogen (979.09), titratable acidity, and pH (943.02) were estimated according to AOAC [8]. Lipid extract [9]. Carbohydrates by difference [10]. Starch content [11]. Polyphenol content [12]. In vitro protein digestibility [13]. The water activity (aw) was measured in the psychrometric equipment for determining water activity (AquaLab, CX2). Color parameters were measured using a HunterLab® ColorFlex Spectrophotometer 45°/0° Standards serial number CX-1719 (HunterLab, Inc., Reston, VA). The amino acid was analyzed using HPLC, UV-Visible detector, quaternary pump, and Nova-Pak C18 column (Waters p/N WAT011695) 3.9 x 300 mm. Pre-column derivation with Phenylisothiocyanate (PITC) to produce Phenylthiocarbamyl Amino Acids-maximum absorbance of about 269 nm and an auto-analyzer. Previously the samples were hydrolyzed with HCl 6 N for 24 h at 110°C according to the method described [14,15]. Tryptophan was determined after the basic hydrolysis with NaOH 6 N for 24 h at 110°C, then was at rest and pH adjustment to 4.2. the amino acid content is calculated using the Millennium program, whereby integrating the chromatographic peaks directly shows the concentration values.

Statistical analysis

The results of the evaluated determinations were subjected to an analysis of variance (ANOVA) with a significance level of 5%, and the means with significant differences were subjected to the means comparison test by the Tukey method using the SPSS [16] statistical package. Version 17, for Windows 2007.

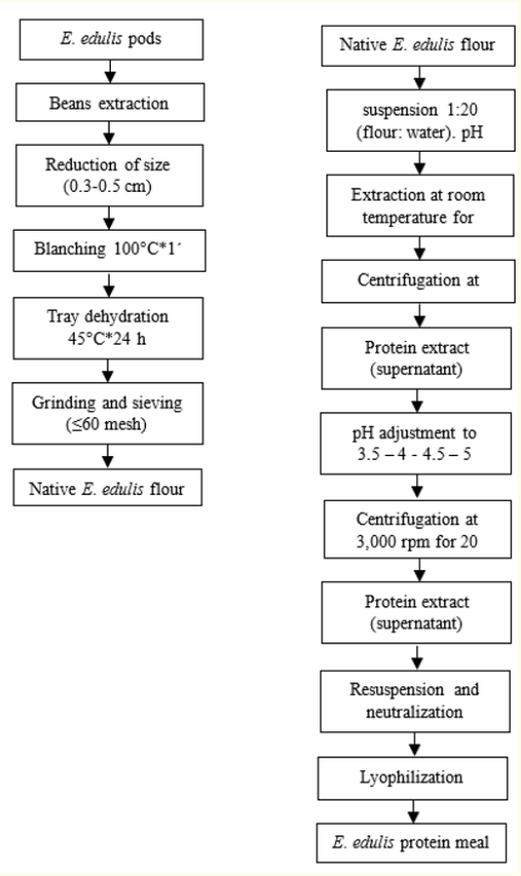

Figure 1: Technological scheme for obtaining native flour and protein from *E. edulis*.

Results and Discussion

Physical properties of pod and beans (Chachafruto) *E. edulis*

The beans had two colors, yellow and red. Like reports from other investigators [4]. There seem to be several morphotypes of Erythrina edulis, some yellow, red, and black (Figure 2).

Figure 2: Tree, pods, and beans of *E. edulis* (chachafruto) harvested in La Azulita, Mérida state, Venezuela.

The physical characterization of the pods of *Erythrina edulis* allowed us to observe (Table 1) that there is a significant difference between this item and other legumes for human consumption. The length of the pods stands out, with minimum values of 31 centimetres and maximum values of 49 cm. Likewise, the weight of pods, on average, weight 160.57 grams. However, the study reported minimum values of 65.80 g and a maximum of 255.5 g. Which represents, on average, an average of grains of 6.72 (minimum value: 4 and maximum: 10). The results show that the weight of the *E. edulis* grains will represent the highest percentage of the total weight of the pod.

Physic parameter	*E. edulis* Pod
Length (cm)	39.66 ± 5.21
Width (cm)	3.07 ± 0.38
Thickness (cm)	2.85 ± 0.37
Whole weight (g) (pod + beans)	160.57 ± 47.32
Pod weight (g)	71.75 ± 15.19
Bean weight (g) (total in the pod)	88.82 ± 34.76
# Beans/pod	6.72 ± 1.72
% Yield (beans function)	55.32 ± 8.39

Table 1: Physical parameters of *E. edulis* (chachafruto) pods harvested in La Azulita, Mérida state, Venezuela.

In the chachafruto beans (Table 2); there was variability in all the parameters evaluated. They were highlighting among them an average length of 4.54 cm. However, the evaluated grains have specific values of 3.18 and 5.48 centimeters. The average weight of grains of 15.11 grams, but within this, there were grains with 5.10 to 25.40 grams. Other important determining variables in grains are the geometric mean diameter, sphericity, and surface area. They are essential for the design of equipment for handling, harvesting, processing, and storing the grain or determining the behavior of the grain for its handling. Various types of cleaning, grading, and separation equipment are designed based on the physical properties of grains or seeds.

Physic parameter	*E. edulis* Beans
Length (cm)	4.54 ± 0.57
Width (cm)	2.50 ± 0.31
Thickness (cm)	2.26 ± 0.25
Geometric mean diameter (cm)	2.94 ± 0.33
Sphericity (cm)	0.65 ± 0.04
Superficial area (cm)	86.67 ± 18.63
Bean weight (g)	15.11 ± 4.85

Table 2: Physical parameters of beans *E. edulis* (chachafruto) harvested in La Azulita, Mérida state, Venezuela.

According to the sphericity results, the chachafruto grains are classified as elongated grains like an ellipse. Estimating these physical properties is essential because they help predict food behavior, generating possible solutions to many problems associated with designing a specific machine (elevators, silos, mills, among others). The variability found in the physical parameters of *E. edulis* evaluated could be influenced by the physiological maturity of the pods, plant conditions, and influence of edaphoclimatic conditions on the development of the pods, among others that it is essential to study to know the behavior of the fruits of this species. Compared with other legumes, for example, *Phaseolus vulgaris*. *E. edulis* has advantages because the harvested fruits are larger and have larger grains, so fewer fruits need to complete a portion of grains of the same weight as *P. vulgaris*.

Native flour production yields *E. edulis*

During the blanching operation, excessive foam formation existed, corresponding to the saponins in the grains, which are characteristic of legumes. After 7 hours of dehydration, a drastic water loss from the material. The rate of water loss is affected by the chemical composition of the samples and the morphology of the cell tissue, in addition to the contact surface of the piece with the hot air of the dehydrator. Once the grains were dehydrated and ground, the yield was 17.30 ± 5.94%. From this, the granulometry of the flour was obtained (Table 3).

Mesh	≥ 30	40	50	60	<60
Particle size (µm)	≥ 595	420	297	250	<250
Native *E. edulis* flour	16.14%	13.65%	16.19%	8.90%	45.12%

Table 3: The particle size of *Erythrina edulis* flours.

The granulometry of the flour is variable, with a higher percentage for the fraction that represents a smaller particle size (<60 mesh), which is important and attractive for commercialization. Some consumers prefer flour as fine as possible because it allows for greater versatility of uses. However, granulometry of 40, 50, and 60 mesh, which for this flour have 38.74 ± 5.94%, may be essential for the development of gluten-free products (biscuits, pasta, pizza dough, among others) that require a different preparation system and that would respond to various diets.

Protein extraction from *E. edulis* flour

The optimum extraction pH for a ratio of 1:20 (Flour: solvent). Time of 24h. Generic precipitation pH of 3 (Considering that pH 3 is not the isoelectric point (pI) of the protein). It was obtained that at pH 11, the highest extraction is performed (38.95 ± 2.87%). From this, pH 11 was used to determine the protein's isoelectric point (Figure 3). The method [7], proposes evaluating the isoelec-

tric point between pH 3 and 7 with unit intervals. However, in this study, the evaluation interval was decreased; firstly, according to the experimental observations, the pH where there is more precipitate is between 4 and 5, this being the interval reported by the bibliography for legumes. Secondly, this allowed us to evaluate more precise pH's; slight variations can alter the isoelectric point. That is, the pI may not be an integer.

Figure 4 denotes that at pH 4.5, a more significant amount of protein precipitated. Therefore, this was used as the isoelectric point. Like studies [17]. Finally, considering that 24 hours of extraction implies a high time consumption. And that at alkaline pH, reactions of hydrolysis and solubilization of compounds that could decrease the yield of the protein content can occur. It was decided to experiment with an extraction time of 1 hour, obtaining the results illustrated in Figure 5. It is observed that the protein content obtained with the extraction of 1 hour is significantly higher than that obtained within 24 hours, 78.42% and 68.71%, respectively. It was proposed to elaborate the final product under the conditions of a 1:20 flour-solvent ratio, 1 hour extraction time, extraction pH 11, and pI 4.5 at room temperature since this implies saving time and improving the yield of the protein extract.

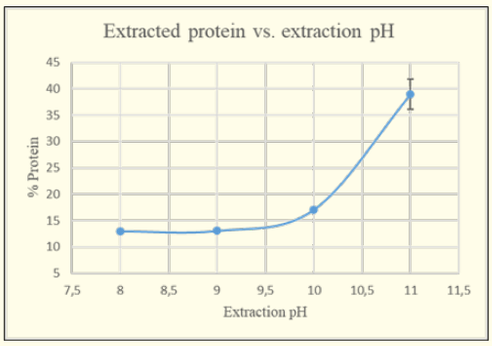

Figure 3: Standardization of the optimum pH for extracting Erythrina edulis proteins.

Gross composition and physicochemical parameters of E. edulis flours

The proximal characterization of the flours showed (Table 4) that both have moisture values that characterize the products as stable and not perishable. The water activity corroborates the stability of these products. In the case of protein flour, low values were obtained that could sometimes cause problems, but no significant changes are expected because the lipid content is low. The native flour registers a considerably important protein content, which positions it very well compared to other legumes. Likewise, it represents a significant contribution in comparison with native flours of cereals, roots, and tubers. However, it presented a total carbohydrate and starch content higher than the values recorded for protein.

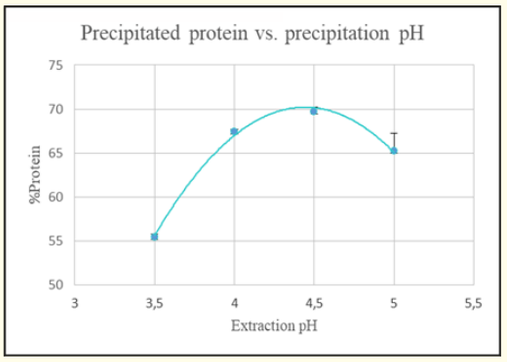

Figure 4: Standardization of the isoelectric point of the Erythrina edulis protein.

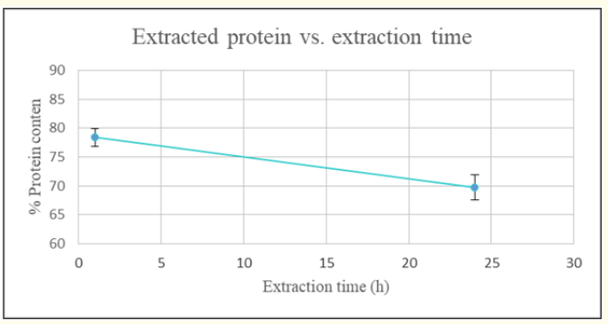

Figure 5: Comparison of the yield of protein extracted at 1 hour and 24 hours

For the protein meal, it is evident that the extraction and precipitation process was adequate to reach a crude protein value of 78%, which allows it to be considered as a protein concentrate, considering that the total carbohydrate content it presented is less than 4% and that meets the moisture and ash requirements established by the Codex Alimentarius for this type of product. If the protein flour has a good flavor, it could be used to formulate products for various diets (celiacs, autistics, athletes, the elderly, dyslipidemic, and diabetics, among others). Also, it could be considered a substitute for animal protein after the necessary studies to ensure such a purpose.

The concentration of polyphenols is significantly lower for the native E. edulis meal than that obtained for the protein meal. Therefore, it can be inferred that these polyphenols were extracted with the proteins and did not remain in the solution but precipitated with them when acidifying. This may be due to protein-polyphenol solid interactions, which also explain the protein flour's brown color (Shown in table 4). In oxygen, polyphenols can be oxidized to the corresponding quinones. Some quinones can polymerize non-enzymatically into brown pigments of high molar mass or react with specific amino acid residues such as lysine, cystine,

Parameter	Native flour *E. edulis*	Protein flour *E. edulis*
Moisture*	11.56 ± 0.16	9.83 ± 0.07a
Total Ash*	3.00 ± 0.10	8.03 ± 0.65
Crude Fat*	1.07 ± 0.03	0,01 ± 0,01b
Crude Protein*	21.92 ± 0.19	78.42 ± 2.83
Total Carbohydrate*	62.45 ± 0.49	3.71 ± 0.39
Starch*	44.12 ± 1.27	-
Energy (per 100g)	347 ± 0.97	329 ± 0.78
Total Polyphenols (mgAc.Gal/g sample)	2.34 ± 0.07	5.12 ± 0.26
Protein digestibility	-	70.43 ± 0.69
a_w	0.445 ± 0.02	0.154 ± 0.01
L*	76.37 ± 0,02	28.45 ± 0.03
a*	1.10 ± 0,02	12.24 ± 0.03
b*	10.61 ± 0,03	10.06 ± 0.03

Table 4: Proximal, functional, and nutritional composition of native meal and protein meal of *E. edulis* (chachafruto).

Results expressed on a dry basis (d,b), N: 3 ± Standard deviation. P = 0.05.

Amino acid	Native *E. edulis flour*	Protein *E. edulis flour*
Essential Amino Acids		
Threonine	4.68 ± 0.04[a]	11.41 ± 0.47[b]
Valine	8.62 ± 0.02[a]	12.23 ± 0.17[b]
Methionine + Cystine	ND	1.04 ± 1.03[b]
Isoleucine	6.30 ± 0.01[a]	7.79 ± 0.44[b]
Leucine	12.77 ± 0.03[a]	20.07 ± 0.61[b]
Phenylalanine + Tyrosine	12.44 ± 0.06[a]	27.64 ± 1.52[a]
Lysine	6.85 ± 0.10[a]	14.70 ± 0.57[b]
Histidine	7.74 ± 0.07[a]	15.25 ± 0.23[b]
Non-essential amino acids		
Aspartic acid	14.16 ± 0.40[a]	29.79 ± 1.05[b]
Glutamic acid	19.99 ± 0.22[a]	46.48 ± 1.18[b]
Serine	6.75 ± 0.01[a]	14.42 ± 0.77[b]
Glycine	5.15 ± 0.02[a]	12.25 ± 0.89[b]
Arginine	7.60 ± 0.05[a]	18.15 ± 0.19[b]
Alanine	8.50 ± 0.08[a]	13.28 ± 0.58[b]
Proline	6.38 ± 0.10[a]	14.02 ± 1.02[b]

Table 5: Amino acid profile (mg/g of sample) of native meal and protein meal of *E. edulis* (chachafruto).

Amino acids expressed on a d,b as mg Aas/g sample. N: 3 ± Standard deviation. P = 0.05.

nd: not detected for cystine in native flour.

methionine, or tryptophan [18]. One way to reduce this collateral effect would be to remove the husk from the grains before making the flour, since the polyphenols in legumes are found mainly in this part of the seed, or to wash the flour with an ethanol-water mixture before processing-extraction of proteins, to remove the most significant amount of polyphenols. The protein digestibility in vitro of the protein meal showed a value higher than 70%. This value is lower than that reported for raw legumes [19], which is around 80%. However, 70% for a product containing 78.4% protein is satisfactory. This digestibility is by to the high content of polyphenols presented by the protein meal and other antinutrients extracted. In vitro protein digestibility, according to the method used [13], correlates 0.90 with in vivo protein digestibility, which is entirely accurate. Based on this, the consumption of 100g of this product has a net use of approximately 55g of protein. This value is more than what the native flour of Erythrina edulis and, indeed, any other legume can provide after being digested.

Total amino acid profile of *E. edulis* flours

The flours evaluated have a substantial composition of essential amino acids, making them attractive food for various diets. The flours contain branched-chain amino acids (leucine, isoleucine, and valine), representing around 47% of the total essential amino acids for native flours and 36% for protein flours. The essential amino acids that contain sulfur (methionine + cysteine) did not reach the reference chemical score value of FAO [20], a predictable result for being scarce in legumes. For lysine (limiting essential amino acid in cereals), the protein flours have a higher proportion than native ones, representing an advantage over other vegetable raw materials. The flours contain phenylalanine and tyrosine, which is vital in the diet of healthy individuals. However, it is crucial to consider those populations with special diets, for example, fenulketonurics. No tryptophan was found, possibly due to significant interferences in the chromatograms of the sample. In some cases, the peak was tiny and unresolved; on other occasions, it did not appear, preventing its correct quantification. It is also important to remember that legumes are a poor source of tryptophan. For non-essential amino acids, aspartic and glutamic acids have a higher amount, a predictable result because the extraction is in an alkaline medium, so there are more probabilities of solubilization of acid amino acid residues.

Evaluating the amino acid profile from a more nutritional point of view, taking protein digestibility into account, and knowing the daily protein and amino acid requirements proposed by the World Health Organization, if a healthy 15-month-old child with an average weight of 11kg [21] with a daily protein requirement of 9.46g, consuming 100g of protein flour would be exceeding their recommended daily protein intake, as well as their daily needs for histidine, isoleucine, leucine, lysine, threonine, and valine. Likewise, for a healthy adult, considering that according to studies published by the Public Health magazine [21], in Latin America, the average weight of an adult is 68kg, he would need 45g of protein to cover his daily intake, however, as mentioned above, 100g of protein

flour provides 55g of net protein. Therefore, it would represent a higher percentage (122%) of the daily requirement.

Conclusion

The physical properties of the Chachafruto beans are an advantage for direct consumption (after cooking). In addition, consuming just a few beans may have health benefits associated with increased satiety and reduced energy intake. Likewise, it favors obtaining native, concentrated, or isolated flours with ideal nutritional properties for a healthy diet. The protein meal obtained showed a varied amino acid profile, with important contents of essential amino acids (except for tryptophan). Protein digestibility of 70% indicates that this vegetable meal is of high biological value. Therefore, it is feasible to suggest it to traditional consumers and consumers with special diets.

Acknowledgements

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Conflict of Interest

The authors whose names are listed in this paper certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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