

Nutritional Value and Energetic Properties of Caimito (*Chrysophyllum cainito* L.) from Southern Nariño, Colombia

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Abstract

Background

Caimito (*Chrysophyllum cainito* L.), a culturally significant fruit from Nariño, Colombia, remains underutilized due to limited scientific characterization. This study investigates its nutritional composition and predicts the metabolic potential of its proteins through in-silico simulations.

Methods

A descriptive analysis was performed on fruit samples from San Andrés de Tumaco, analyzed at the CICTA Food Laboratory using AOAC-certified methodologies. Protein metabolism was simulated via bioinformatics tools to estimate peptide-derived energy contributions.

Results

Caimito is a hydrating, low-calorie fruit (90.97% moisture, 29.41 kcal/100 g), with carbohydrates (8.09 g) and proteins (0.76 g) as primary energy sources. It contains no detectable fats and provides 3.00 g of dietary fiber, supporting digestive health. In-silico analysis identified bioactive peptides with energy contributions ranging from 7.92 to 17.6 kcal, suggesting potential dietary applications.

Conclusion

Caimito is a refreshing, functional fruit suitable for hypocaloric diets. While its low macronutrient density limits its role as a staple food, its bioactive properties and cultural significance underscore its potential for functional food development. Further research on preservation methods and additional applications is necessary to enhance its nutritional and commercial viability.

Introduction

The caimito (*Chrysophyllum cainito* L.), commonly known as star apple, is a tropical fruit native to the Americas [1]. In Colombia, it holds notable cultural and dietary importance, especially in the southern Pacific region of Nariño, where its consumption is deeply integrated into local traditions and culinary practices [2]. Despite its prominent role in the region's cuisine, the caimito remains underutilized compared to other tropical fruits, primarily due to the limited research on its nutritional profile, health benefits, and potential applications in the development of functional foods [3]. Renowned for its vibrant coloration, distinctive texture, and sweet flavor, the caimito is a highly sought-after but seasonally transient addition to local diets. Its brief harvest window of approximately 15 days, coupled with rapid post-harvest deterioration, presents significant challenges to its wider commercialization and preservation [4]. These limitations are further compounded by the environmental conditions of its primary cultivation regions, where high humidity and temperatures accelerate spoilage, severely restricting its market potential [5].

Nutritionally, the caimito is a rich source of water and carbohydrates, complemented by moderate amounts of protein and dietary fiber [6]. Micronutrient analysis has revealed its high levels of potassium and calcium, while phytochemical investigations have identified bioactive compounds such as flavonoids and phenolic acids [7]. These compounds are renowned for their powerful antioxidant properties, which help protect cellular health by reducing oxidative stress [8]. Emerging research further indicates that the fruit may offer additional therapeutic benefits, including anti-inflammatory, antidiabetic, and antimicrobial effects, making it a promising candidate for nutraceutical applications [9]. Despite its promising attributes, research on the full nutritional and functional potential of the caimito remains limited [4, 10]. Unlike commercially dominant fruits, the caimito has not received substantial investment in agricultural technology or post-harvest processing innovations. This lack of attention has resulted in a significant gap in scientific knowledge, particularly concerning its protein profile, metabolic properties, and potential applications in contemporary dietary interventions [3].

In this context, with global health challenges such as the rising prevalence of metabolic disorders and malnutrition, there is a growing demand for nutrient-dense, functional foods derived from plant-based sources [11]. The bioactive properties and plant-derived protein content of the caimito align with these trends, offering promising opportunities to address specific dietary needs, particularly in regions with limited access to high-quality animal proteins [12]. Plant-based proteins, recognized for their roles in promoting cardiovascular health, regulating metabolism, and potentially reducing cancer risk, are increasingly valued as essential components of sustainable, health-promoting diets [13]. Therefore, the caimito's potential contribution to this domain remains largely unexplored, emphasizing the need for further research.

Building on its nutritional profile and bioactive compound content, this study aimed to address existing knowledge gaps by conducting a comprehensive evaluation of the caimito's nutritional composition and investigating the metabolic potential of its proteins through bioinformatics tools. By integrating laboratory analyses with in silico simulations, the research seeks to provide a deeper understanding of the fruit's nutritional and functional attributes. Ultimately, the findings aim to promote the incorporation of caimito into both traditional and contemporary diets, contributing to the diversification of food systems, the development of functional foods, and the enhancement of food security in regions like Nariño, Colombia.

Methods

Study design

This study employed an integrative approach, combining quantitative and qualitative methods within a descriptive framework. A total of 1 kg of optimally ripened caimito fruits were procured from local markets and street vendors in San Andrés de Tumaco, Nariño, Colombia. The fruits underwent meticulous examination to exclude samples with any physical or chemical damage, ensuring the integrity and reliability of subsequent analyses.

To enhance representativeness and accessibility during sample selection, a purposive statistical sampling strategy was utilized. Furthermore, *in silico* analyses were conducted to complement the experimental findings, offering deeper insights into the metabolic potential of the proteins present in the fruit. This dual approach aimed to provide a robust and comprehensive understanding of caimito's nutritional and functional properties.

Laboratory analysis

Nutritional evaluations were performed at the CICTA Food Laboratory of the Universidad Industrial de Santander (UIS), following AOAC-certified methodologies to ensure accuracy and reproducibility. Moisture and ash contents were determined using gravimetric techniques. Protein content was quantified using the volumetric Kjeldahl method, while crude fiber and total dietary fiber were measured through acid-base hydrolysis and enzymatic-gravimetric analysis, respectively. The total carbohydrate content was calculated using the following mathematical expression:

$$\%CT = 100 - (\%H + \%C + \%P + \%G)$$

Where H, C, P, and G represent the percentages of moisture, ash, protein, and fat, respectively. The caloric value was estimated following the guidelines outlined in Article 11 of Resolution 810 of 2021 and the FAO/INFOODS 2012 framework.

On the other hand, the mineral content, including sodium, calcium, iron, magnesium, and potassium, was assessed using atomic absorption spectroscopy, while vitamin levels were determined through liquid chromatography. Fat and fatty acid profiles were analyzed using gas chromatography with a flame ionization detector (FID), in accordance with NTC 4967:2014 standards.

In-Silico analysis

For protein analysis, the UniProt database (<https://www.uniprot.org>) was utilized. A random selection process identified five proteins, each ranging from 100 to 500 amino acids, with potential metabolic relevance. Enzymatic cleavage sites for trypsin and pepsin were determined using the Peptide Cutter tool (https://web.expasy.org/peptide_cutter/), resulting in 29,888 cleavage sequences [14]. Subsequently, these sequences were filtered to retain only those with lengths between 20 and 40 amino acids, yielding a subset of 1,404 sequences. This subset was analyzed using R statistical software to estimate the energetic potential of the proteins. The energy release (kcal) associated with metabolizing 100 g of these proteins was calculated to evaluate their metabolic significance [15]. The energy content was calculated using the following mathematical expression [16]:

$$Kcal = \frac{N^{\circ} aa \cdot 110 Da}{1000} \cdot 4 g$$

Where N° aa represents the number of amino acids in the protein sequence.

Statistical analysis

Both descriptive and inferential statistical methods were employed to ensure the robustness and reliability of the laboratory and *in-silico* data. Normality was evaluated using the Shapiro-Wilk and Anderson-Darling tests, with a significance level set at $p < 0.05$. Descriptive statistics, such as mean, median, and standard deviation, were utilized to summarize the general properties of the fruit. All statistical analyses were conducted using Prism 8.0.2 (GraphPad Software Inc., CA, USA) and R v4.3.2 (R Core Team, 2021) [17].

Results

Caimito (*Chrysophyllum cainito* L.) production in Colombia is primarily concentrated in the Amazonas department, which leads the country in output. However, as illustrated in Fig. 1, the department of Nariño has experienced a notable increase in caimito cultivation in recent years, establishing itself as the second-largest producer nationwide. By 2022, the planted area in Nariño expanded to 48,000 hectares (ha), resulting in a total yield of 130.80 tons of caimito. Within the department, the municipality of Ricaurte is particularly notable for its high concentration of caimito plantations, achieving an impressive yield of 12.5 tons per hectare (ha/ton) [18]. This significant growth underscores the region's increasing interest in caimito cultivation, positioning the fruit as a potential cornerstone of local agriculture and cultural heritage.

Nutritional analysis

The nutritional analysis of caimito (Fig. 1.D) underscores its value as a nutritious and low-calorie food source. The fruit demonstrated a high moisture content ($90.97 \pm 0.02\%$) and a low energy density of 29.41 kcal per 100 g. Among its macronutrients, carbohydrates were the primary contributors to energy, totaling 8.09 ± 0.00 g per 100 g, followed by proteins at 0.76 ± 0.01 g. Notably, no fats were detected, confirming that the fruit's caloric content is entirely derived from carbohydrates and proteins. These properties position caimito as a favorable choice for inclusion in low-calorie diets.

Fiber analysis revealed a total dietary fiber content of 3.00 ± 0.14 g and a crude fiber content of 0.01 ± 0.00 g, indicating that caimito provides a moderate fiber contribution with a relatively low proportion of resistant structural carbohydrates. This positions the fruit as a beneficial addition to daily diets, particularly for supporting digestive health. In terms of micronutrients, potassium (72.43 ± 2.08 mg) and calcium (13.87 ± 0.19 mg) were identified as the

predominant minerals. Although their concentrations are moderate compared to other mineral-rich foods, they offer notable health benefits, including maintaining electrolyte balance and supporting bone health. These attributes further enhance the overall nutritional value of caimito, making it a valuable component of a balanced diet.

In-Silico Analysis

The computational analysis of caimito protein metabolism utilized bioinformatics tools to simulate enzymatic digestion. The peptide sequences generated from enzymatic cleavage were further examined (Fig. 2A), and three-dimensional models of the proteins and peptides were constructed to visualize potential metabolic pathways and outcomes (Figs. 2B-F). Additionally, the energy contributions of each peptide were assessed, providing a detailed characterization of their metabolic potential (Fig. 2G).

The energy density distribution of the peptide sequences exhibited a bimodal pattern with two distinct peaks (Fig. 2H). The first peak, centered around 10 kcal, represented sequences with lower energy values, while the second peak, at approximately 15 kcal, corresponded to sequences with higher energy contributions. This distribution indicates the presence of subgroups of peptides, distinguishable by their metabolic characteristics and energy-releasing capacities. On average, the peptides contributed 13.24 kcal per 100 g of caimito. The energy values varied between 7.92 and 17.6 kcal, likely due to differences in the size and amino acid composition of the peptide sequences (Fig. 2I).

Discussion

Caimito (*Chrysophyllum cainito* L.), a traditional fruit native to the southern Pacific region of Nariño, plays a vital role in the cultural and dietary heritage of the area. Its consumption extends beyond mere nutritional value, embodying local dietary practices and serving as a cornerstone of cultural traditions within the region's food landscape [19]. The nutritional profile identified in this study underscores its potential as a functional food, offering promising health benefits and contributing to the diversification of the local diet.

In this context, comparing the nutritional composition of caimito from this study with previous research reveals variability in nutrient profiles. These differences may be influenced by various factors, including cultivation conditions, harvesting methods, and differences in analytical methodologies [20]. Despite this variability, it is possible to establish approximate ranges for key nutritional components, providing a comprehensive overview of caimito's nutritional value. For instance, the fruit's macronutrient profile is predominantly composed of water, with a high moisture content ($90.97 \pm 0.02\%$) that underscores its classification as a hydrating, low-calorie food, providing just 29.41 kcal per 100 g. This caloric value is substantially lower compared to other caimito varieties (e.g., 64 kcal per 100 g) [21], positioning it as an excellent option for hypocaloric and weight-management diets. According to Colombian nutritional guidelines, the daily consumption of caimito could fulfill approximately 1.9% of the caloric requirements for children aged six months to four years and 0.96% for older children and adults. These findings further highlight its role as a light energy supplement with potential applications in balanced dietary regimens [22].

Regarding macronutrients, the protein (0.76 g) and carbohydrate (8.09 g) content in caimito are lower than those reported in other varieties (e.g., 1.0 g and 11 g, respectively) [23]. Despite these differences, the fruit can contribute approximately 1.9% of the recommended daily protein intake for children and 0.98% for adults, along with 3.5% and 1.7% of the daily carbohydrate requirements, respectively [24]. These properties, combined with its negligible fat content, solidify caimito's position as a health-promoting, low-calorie dietary choice. As essential organic compounds, carbohydrates and proteins not only serve as primary energy sources but also play key roles in determining the flavor, texture, and structural integrity of foods [25].

Dietary fiber, a vital component for digestive health, was measured at 3.00 ± 0.14 g, representing a moderate contribution compared to other tropical fruits [21, 23]. According to Ministry of Health guidelines, this fiber content can fulfill up to 13.5% of the daily recommended intake for young children and 6.7% for adults. Fiber is essential for promoting healthy intestinal transit, regulating glucose levels, and lowering cholesterol, while also providing a natural laxative effect that supports overall digestive health [24]. Crude fiber content was minimal (0.01 g), indicating a low proportion of structural carbohydrates. Although different from dietary fiber, as noted by Vilcanqui-Pérez and Vilchez-Perales [26], crude fiber also contributes to accelerating intestinal transit and reducing the absorption of cholesterol and glucose. These attributes highlight caimito as a promising fruit for promoting digestive health and aiding in the prevention of cardiovascular diseases [27].

Regarding micronutrients analysis, calcium and iron contents were consistent with those reported in other studies, which reinforces the idea that these minerals have a stable presence in caimito [28]. However, other micronutrients such as magnesium, sodium, and potassium, which were measured in this study, showed notable variations, which suggests that its concentration in the caimito could vary depending on the growing conditions and the methods of analysis used [29]. Of these, potassium (72.43 ± 2.08 mg) emerged as the most abundant, underscoring its importance in regulating blood pressure and maintaining electrolyte balance. Calcium (13.87 ± 0.19 mg) and magnesium (8.72 ± 0.19 mg) also contribute to bone and muscle health [30]. While caimito may not be as nutrient-dense as some other tropical fruits, it still serves as a valuable dietary supplement for certain micronutrients [31].

The susceptibility of caimito to oxidation, driven by environmental exposure and enzymatic activity (e.g., polyphenol oxidase), represents a major challenge. Oxidation adversely affects the fruit's sensory qualities and accelerates spoilage, limiting its shelf life. Therefore, future research should focus on developing preservation and processing methods to extend its shelf life and improve its accessibility [32].

The bioinformatics analysis of caimito proteins revealed peptide sequences with varying energy contributions (Fig. 1G). These sequences displayed a bimodal energy density distribution, with one group of peptides providing lower energy (10 kcal) and another offering higher energy (15 kcal). Such a

distribution indicates that caimito proteins could be tailored to meet specific dietary needs: lower-energy peptides are suitable for weight-loss or restricted diets, while higher-energy peptides could support individuals with higher energy demands, such as athletes or those in need of weight gain [33].

The average energy contribution from peptides was 13.24 kcal per 100 g of sample, with minimal variability. These peptides could be incorporated into functional foods designed to meet specific dietary goals. For example, larger peptides with higher energy outputs might benefit individuals seeking to increase their energy intake, while smaller peptides could be used in weight management strategies without compromising lean mass [36]. Additionally, proteins are known to influence diet-induced thermogenesis (DIT), which affects metabolic efficiency. The peptides identified in this study could be further explored for their potential to enhance DIT and support weight management, lean mass retention, and overall metabolic health [34].

Protein modeling and metabolic simulations provide valuable insights into the energy balance and metabolic markers associated with caimito proteins. These tools enable the exploration of protein functionality in energy balance and metabolic markers, with potential applications in dietary interventions and health optimization. Future research should focus on expanding the knowledge of the bioactive properties of caimito, with an emphasis on its integration into processed foods and dietary supplements to optimize health outcomes [35].

Conclusions

The Caimito (*Chrysophyllum cainito* L.) is a fruit characterized by its high moisture content and low caloric density, making it an ideal choice for inclusion in hypocaloric diets. Its moderate dietary fiber content offers notable digestive health benefits, including improved intestinal transit and reductions in blood cholesterol and glucose levels. However, its relatively low protein, carbohydrate, and micronutrient content limits its role as a primary nutrient source. Instead, caimito is better suited as a complementary dietary supplement, enhancing the overall nutritional profile of a balanced diet.

The *in-silico* analysis of caimito proteins revealed valuable insights into their metabolic potential. The identified peptides demonstrated variable energy contributions, making them adaptable for different dietary needs—ranging from energy-restricted diets to those requiring higher caloric intake. These findings suggest that caimito holds promise as a foundation for developing functional foods and dietary supplements tailored to specific health and nutritional goals.

Despite its nutritional and cultural significance, caimito faces several challenges, including seasonality, rapid degradation, and relatively low nutrient density compared to other tropical fruits. Overcoming these limitations will require the development of effective post-harvest management strategies and preservation technologies aimed at extending shelf life and improving marketability. Moreover, further research into other parts of the caimito plant, such as its leaves, may reveal bioactive compounds with therapeutic or functional properties, offering additional value to this underutilized species.

Integrating caimito into broader dietary practices presents an opportunity to improve food security, public health, and economic development in the southern Pacific region of Nariño. With innovations in cultivation, processing, and commercialization, caimito could realize its full potential, contributing to the sustainable development of local communities while preserving a culturally significant agricultural resource.

Declarations

Competing interests

The authors declare no competing interests.

Author Contribution

S.C.R.-L. and D.P.O.-T. were responsible for data collection and drafting the initial manuscript. A.L.D.-B. and M.H.Z.-L. also participated in data collection, and together wrote the final version of the manuscript with contributions from S.C.R.-L. and D.P.O.-T. P.A.A.-B. and J.P.G.-L. carried out the manuscript review, follow-up, and provided key conceptual contributions throughout the development of the work. All authors reviewed and approved the final manuscript.

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Figures

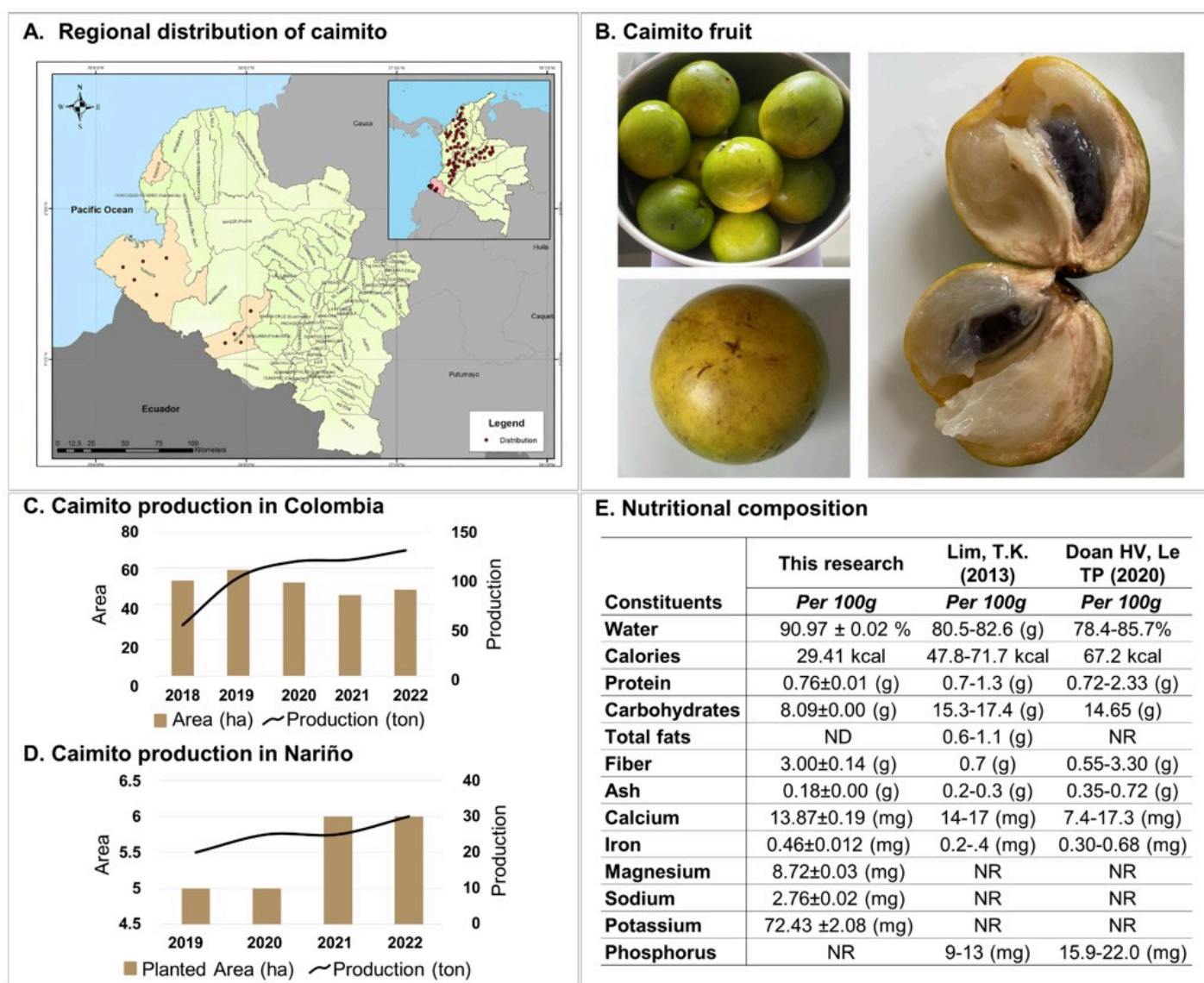


Figure 1

Chrysophyllum cainito and nutritional value. A. Geographical distribution of Caimito production in Nariño. B. Caimito fruits samples obtained in Tumaco, Nariño. C. National production of caimito, with Amazonas and Nariño as the primary producing departments (Source: Municipal Agricultural Evaluations (EVA) – Advisory Office for Planning and Foresight – Ministry of Agriculture and Rural Development) [29]. D. Regional production trends in Nariño over the past few years (Source: Municipal Agricultural Evaluations (EVA) – Advisory Office for Planning and Foresight – Ministry of Agriculture and Rural Development) [29]. E. nutritional content of Caimito, based on data from this study and existing literature, The table provides average values and standard deviations (SD). Non-detected components are marked as ND, and those not reported as NR (Source: Laboratory of Universidad Industrial de Santander, UIS, 2022).

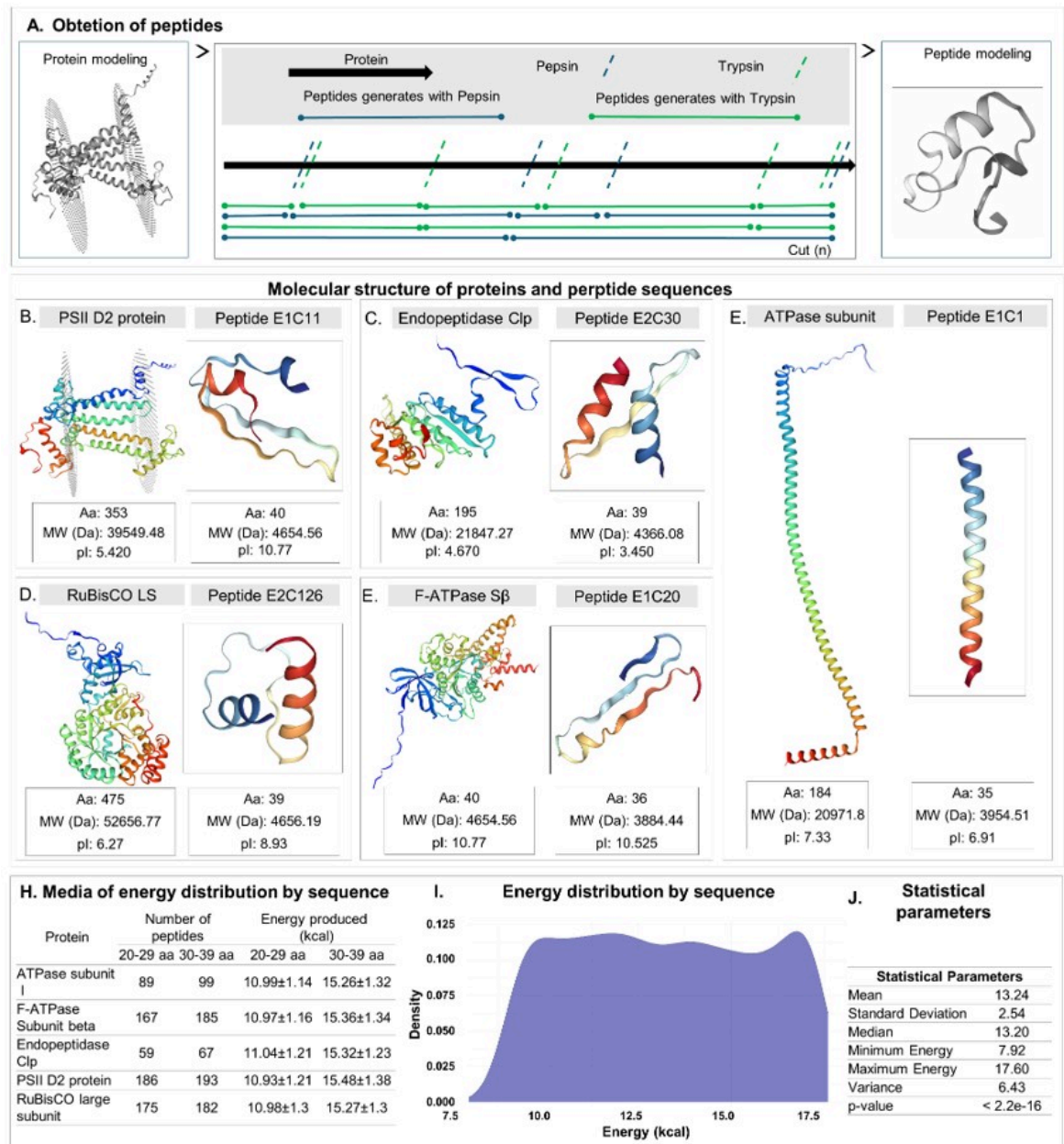


Figure 2

Computational analysis of protein digestion and energy distribution in caimito (*Chrysophyllum cainito* L.). A. Experimental workflow for simulating enzymatic cleavage using trypsin and pepsin with the Peptide Cutter tool from ExPASy. B–F. Three-dimensional visualizations of selected proteins and the peptides generated through enzymatic cleavage with trypsin (E1) and pepsin (E2). G. Energy contributions of protein sequences following enzymatic digestion. H. Energy density distribution graph for amino acid sequences post-digestion. I. Summary of key statistical parameters (p-value < 2.2e-16).

Supplementary Files

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