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Sustained antioxidant properties of yacón (Smallanthus Sonchifolius) for digestive health improvement

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Abstract

Smallanthus sonchifolius (known in Colombia as yacón) is a vegetable characterized by high polyphenol and fructooligosaccharides (FOS) content, which confer antioxidant properties beneficial in metabolic, neoplastic, and cardiovascular diseases. The primary contribution of yacón lies in its ability to promote multiple health benefits, including immunoregulation, anti-inflammatory effects, and antioxidative activity. FOS are short-chain fructans composed of linear chains of fructose molecules that are not enzymatically digestible in the upper digestive tract. These compounds are naturally present in yacón, providing carbohydrates that meet basic daily energy requirements (approximately 2200 Kcal) while also offering antioxidant and prebiotic properties. In this study, the concentration of polyphenols, flavonoids, and antioxidant potential in yacón was examined, with particular focus on how the efficiency and speed of extraction influence absorption processes. The relationship between total flavonoid content and redox activity demonstrated a close correlation, with higher flavonoid concentrations associated with increased redox activity. This highlights the significant capacity of yacón as a natural source with potential applications in the biological field, especially for anti-inflammatory, anti-glycemic, and anti-lipidemic activities. Further in vitro and in vivo assays are necessary to determine the effective applications of polyphenols extracted from natural sources, including yacón, to better understand their therapeutic potential and optimal extraction methods.

Keywords: Antioxidants, Elongated extraction, Polyphenols, Yacón.

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1. Introduction

The World Health Organization (WHO) estimates that colorectal cancer will generate a significant morbidity burden (63% increase) and 1.6 million deaths per year (>73%) [1]. Diabetes is responsible for 1.5 million deaths, with approximately 48% of these deaths occurring in patients under 70 years of age [2]. Obesity prevalence ranged from 4 to 18% in the last three decades, affecting mainly the young population (5 – 19 years old) [2, 3]. Despite the increase in morbidity and mortality rates due to unhealthy eating habits, studies continue to focus on traditional therapeutic objectives, such as physical activity and following a healthy diet without sugar or saturated fats [1, 2]. There is a direct correlation between the consumption of antioxidant natural products and the diminishing occurrence of the previous diseases [1, 2].

Health benefits of multiple phytochemical micronutrients have generated an investigation into foods used in everyday life, aiming at a nutritional protective role. Some of these beneficial components are found in *Smallanthus sonchifolius* (a tuber known in Colombia as yacón). This tuber contains a high content of fructooligosaccharides and polyphenols that can regulate metabolic, neoplastic, and cardiovascular diseases [4]. Based on recent bibliographical research (ProQuest Central, Web of Science, Ovid, Google Scholar consulted up to July 2025), data evaluating elongated or sustained antioxidant activity and FOS content in food supporting digestive health are scarce. The present work focuses on highlighting the theoretical benefits of yacón consumption concerning polyphenols and their antioxidant characteristics. It also aims to quantify total polyphenols and flavonoids in Colombian white yacón with elongated extractions and to test its antioxidant potential.

1.1. Characteristics and Components of Yacón

Yacón (*S. sonchifolius*) is cultivated in different South American countries, Europe, and Western Asia. It comprises metabolic, prebiotic, and antioxidant properties, leading to multiple health benefits. Yacón provides therapeutic and nutritional reinforcement in diabetes mellitus, cancer, and Alzheimer's disease [4]. The etymological meaning of yacón is yaku, a Quechua (native Colombian dialect) word that means "aqueous," referring to the high percentage of water content (>70%) [3]. This plant has a branching system with stems of 2 to 2.5 meters high and produces starchy roots weighing up to 10 kg [1]. The root is the part that gathers the most important proportion of water, macro and micromolecules [2, 3]. More than 94% of the fresh root is composed of carbohydrates, mainly fructooligosaccharides (FOS), oligofructose, and fructose. FOS are fructans that consist of short linear chains of fructose molecules, which are not enzymatically digestible in the upper digestive tract [4-6]. Sources of FOS are garlic, onion, asparagus, artichoke, banana, wheat and yacón [1].

When FOS reaches the colon, it undergoes intestinal microbial fermentation, exhibiting prebiotic activity and stimulating the proliferation of bifidobacteria. FOS increases the production of short-chain fatty acids (SCFA), favoring the growth of health-promoting bacteria and reducing putrefactive bacteria; this action improves the health of the host and stimulates the immune system [6]. FOS content, in yacón, benefits metabolic conditions, contributes to palatability and acceptance due to fructose content, without stimulating insulin production, and involves slow fructose metabolism without altering glucose concentrations [6]. Different animal and human studies have correlated positive effects of FOS, finding that yacón (340 mg FOS/kg/d) improved antioxidant activity (0.14 g/FOS/kg/day), increased serum levels of anti-inflammatory markers 4, and IgA, decreasing the likelihood of gastrointestinal disorders [4, 6, 7].

1.2. Effects of Yacón FOS on Obesity

FOS has positive effects in the inhibition of lipolysis, increased mobilization of triglycerides, and adipogenic differentiation. *In vitro* studies report that SCFA reduce cholesterol synthesis by decreasing the hepatic activity of the enzymes 3-hydroxy-3-methylglutaryl-CoA synthase and 3-hydroxy-3-methylglutaryl-CoA reductase [4]. According to *in vivo* testing, an experimental study with 44 rats receiving isotonic substances (0.9% sodium chloride) accompanied by yacón and eggplant extracts showed a reduction in total cholesterol, low-density lipoproteins (LDL), and triglyceride levels compared to control groups [4, 8].

A recent study evaluating antioxidant effects and high fructose and cholesterol diets in rats supplemented with yacón polyphenols showed a positive connection and lower metabolic and lipid markers [9]. Main results yielded lower levels of glutathione, malondialdehyde, and superoxide dismutase and increased catalase levels. They also correlated with lower concentrations of triglycerides (TGC), glucose, and urea, highlighting the antioxidant effect of polyphenols from aqueous extract of yacón leaves [9].

1.3. FOS in Cholesterol Metabolism

FOS are related to augmented gastrointestinal peptide secretion through the production of SCFA, acting as appetite modulators and increasing satiety [10]. Excess fructose intake increases postprandial triglyceride levels, total cholesterol, and LDL cholesterol, inducing greater atherogenic capacity. This is due to the transformation of excess fructose into fatty acids, which favors fructose malabsorption and non-alcoholic fatty liver disease [9]. Figure 1 represents a summary of functions connecting FOS to different metabolic processes.

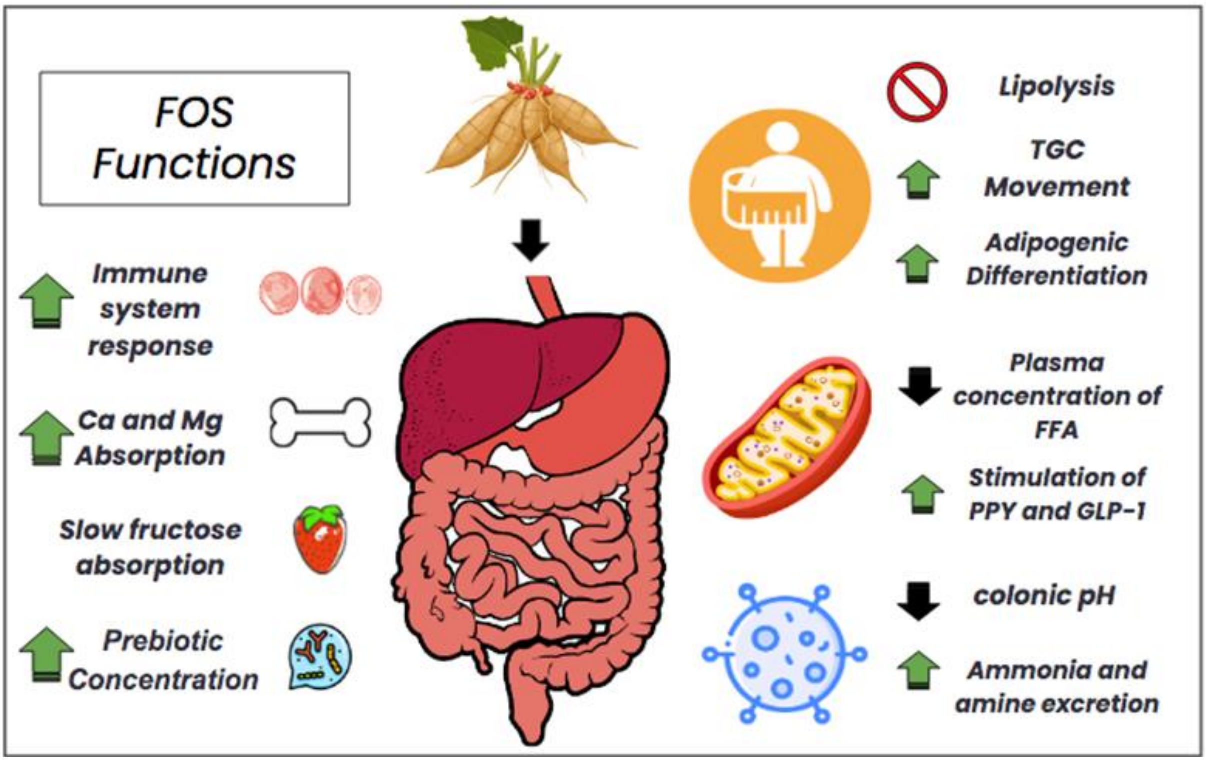

Figure 1.
Fructooligosaccharides (FOS) have benefits in humans. TGC: triglycerides, FFA: Free Fatty Acids, PPY: Neuropeptide Y, GLP-1: glucagon-like peptide-1.

1.4. Role of the intestinal microbiota

Gut microbiota is intimately involved in various intestinal biological functions, such as defense against pathogens, immunity, development of intestinal microvilli, and degradation of indigestible polysaccharides [4, 6]. Studies suggest that gut microbiota plays a crucial role in the development of fat mass and changes in energy balance [4, 6, 9, 11]. Conversely, poor gut microbiota contributes to generating low-grade inflammation that characterizes metabolic disorders through mechanisms associated with intestinal barrier dysfunction [11]. Yacón can potentially stimulate the production of bifidobacteria capable of reestablishing microbiota, modifying not only intestinal transit but also favoring mucosal hyperplasia, increasing surface area, and improving ionic solubility aspects. These actions enrich the process of absorption and utilization of nutrients [4, 6].

1.5. Effects of FOS on metabolic diseases

Yacón FOS syrup consumption promotes glucose uptake in peripheral tissues and improves insulin sensitivity through SCFA production [12]. Intestinal microflora and host metabolism generate a favorable environment for the production of SCFA by the fermentation of FOS. SCFAs are rapidly absorbed in the colon and transported to the blood, allowing for the performance of different physiological functions [13, 14]. The impact generated by SCFA leads to a reduction of free fatty acids through acetate, decreases gluconeogenesis by increasing AMPK expression in the liver, and supports PPY and GLP-1, stimulating insulin secretion and inhibiting glucagon secretion in the pancreas; therefore, it improves plasma glucose levels [12-14].

Diabetes mellitus is a complex disease characterized by a major disturbance in the metabolism of carbohydrates, fats, and proteins due to deficient insulin secretion. Mammalian α-amylase is a prominent enzyme in pancreatic juice; it breaks down large insoluble starch molecules into absorbable molecules like maltose [15]. The α-glucosidase enzyme, on the other hand, is anchored in the brush border of the small intestine mucosa; it catalyzes the final digestion step of starch and disaccharides abundant in human diets. Inhibitors of α-amylase and α-glucosidase, such as FOS, delay carbohydrate breakdown in the small intestine and decrease postprandial blood glucose excursion levels in diabetic patients [15]. Thus, the inhibition activity against these enzymes can be used as a therapeutic approach to treat diabetes.

1.6. Effects on Neoplastic Diseases

FOS promotes bifidobacteria growth, leading to a decrease in the expression of xenobiotic metabolizing enzymes and stimulating the immune system in the colonic mucosa [13, 14]. These effects generate a reduction in cell proliferation, number, and multiplicity of preneoplastic lesions and invasive adenocarcinomas [14]. Clinical findings report the role of SCFA in limiting inflammation, lowering the pH in the colon, and favoring the excretion of elements such as ammonia and amines, thereby supporting the regulation of the local immune response present in neoplastic diseases [15, 16].

FOS can indirectly influence immune activity through SCFA production, modifying gut microbiota composition, promoting a state of immune tolerance, and modulating interleukin (IL) production and natural killer (NK) cell activity [4, 16]. Natural plant compounds, such as fructans, FOS, and polysaccharides, can activate specialized immune cells (macrophages, dendritic cells, lymphocytes, and neutrophils) by mimicking pathogen-associated molecular patterns that bind toll-like receptors (TLRs), leading to immunomodulatory effects. TLR-mediated activation of NK cells can promote interferon-γ (IFN-γ) production, leading to increased antitumor cytotoxicity [4].

2. Methods and Materials

2.1. Reagents and Chemicals

Ethanol, Folin-Ciocalteu reagent, and sodium carbonate were acquired from PanReac AppliChem, ITW Reagents (Darmstadt, Germany). Aluminum chloride and sodium nitrite were obtained from LOBA Chemie (Mumbai, India), and sodium hydroxide from EMSURE Merck (Darmstadt, Germany). Reference standard quercetin was obtained from MP Biomedicals (California, USA). Ascorbic acid standard and DPPH (2,2-Diphenyl-1-picrylhydrazyl) were purchased from Merck KGaA (Darmstadt, Germany).

2.2. Sample Preparation, Polyphenol and Flavonoid Extraction

Fresh Colombian *Smallanthus sonchifolius* (white yacón) was purchased in Villamaría (Caldas), Colombia. All samples were cleaned with deionized water and dried. The fresh pulp was separated completely from the peels. White yacón pulp, in chopped portions of 5 g, was mixed with 20 mL of aqueous ethanol (80%), stirred (DRAGON LAB, Beijing, China) for 20 minutes at 500 rpm, and allowed to sit for 24 hours (short extraction) and 144 hours (prolonged extraction) in the dark. Exactly 15 mL of each sample was centrifuged (Hermle Z 206 A, Wehingen, Germany) at 3500 rpm for 10 minutes at room temperature. The supernatant was retrieved and refrigerated at 2 °C until further testing.

2.3. Total Polyphenol Quantification

The polyphenol content was determined spectrophotometrically following the Folin-Ciocalteu (F-C) reaction. From the supernatants, 500 µL of each sample was mixed with 500 µL of deionized water and 1.0 mL of the F-C reagent (10%). After 1 minute, 2.0 mL of sodium carbonate (Na_2CO_3) at 3.5% was added and vortexed [17]. All samples, in triplicate, were reacted for 90 minutes in the dark. The evaluation of absorbance for total polyphenol content (TPC) calculations was measured at 655 nm (UV/VIS Optizen POP®, Daejeon, South Korea). All data were calculated based on a calibration curve using a gallic acid standard. TPC is expressed as milligrams of gallic acid equivalent per 100 grams of fresh sample (mg GAE/100 g).

2.4. Total Flavonoid Content

Total flavonoid content in yacón is determined based on the aluminum chloride ($AlCl_3$) colorimetric assay [17]. Amounts of 0.5 mL of each extract were mixed with 2.0 mL of distilled water. Each solution reacted with 150 µL of sodium nitrite ($NaNO_2$) (5%), followed by a 5-second vortex after 5 minutes. Subsequently, 150 µL of $AlCl_3$ (10%) was added to each solution, followed by the same agitation and reaction time. Finally, 1.0 mL of sodium hydroxide (NaOH) (1 M) and 1.2 mL of distilled water were added with vortexing, and a 5-minute reaction was allowed. Assays were performed in triplicate. The total flavonoid content is reported as milligrams of quercetin equivalents (QE) per 100 grams of fresh pulp (mg QE/100 g FP).

2.5. DPPH Assay for Radical Scavenging - Antioxidant Activity

The DPPH radical scavenging test is one of the most useful techniques to evaluate the antioxidant activity in polyphenols extracted from natural products. The DPPH compound is a stable free radical in methanol. Volumes of 2.0 mL of DPPH (100 µM) prepared in pure methanol were mixed with 200 µL of each diluted (1:5) extract and allowed to react in the dark at room temperature for 30 minutes. The antioxidant activity of the phenolic extracts from fresh white yacón was measured via spectrophotometry at 517 nm [18]. The control curve was prepared with concentrations of a comparable reference ascorbic acid (Merck KGaA, Darmstadt, Germany) in a concentration range of 50 to 600 µg/mL. The slope obtained from the calibration curve was used for the calculation of the inhibitory concentration ($IC_{50\%}$) when 50% of the antioxidant component is reduced. Results were determined based on the equation:

$$\% \text{ scavenging DPPH free radical} = (ABS_{Control} - ABS_{Extracts}/ABS_{Control}) * 100\%$$

The antioxidant activity of phenolics from white yacón is expressed as milligrams of ascorbic acid equivalents per 100 grams of fresh or dehydrated pulp or seeds (mg AAE/100 g). All experimental runs were performed in triplicate.

2.6. Statistical Analysis

Results were tested based on initial conditions of normality and homogeneity. All data were statistically evaluated using analysis of variance (ANOVA), followed by a Tukey test. The statistical significance was set considering values for *p*

< 0.05 [19]. IBM SPSS Statistics software version 20 (Armonk, NY – USA) was used for all data evaluations. All analyses were performed in triplicate; TPC, TFC, and DPPH values are expressed as mean ± standard deviation (SD).

3. Results

3.1. Sample Collection and Polyphenol Extraction

Fresh samples of white yacón were collected from urban markets in Villamaría (5°02′44″N 75°30′55″W) in the state of Caldas, located at 1,920 meters above sea level in the Central Andean mountains of Colombia.

Figure 2.
Smallanthus sonchifolius (white and pink yacón) from Villamaría (Caldas) – Colombia.

Color is the main physical difference between these two varieties of Colombian yacón. All other outer and inner characteristics are very similar. This tuber is found in local markets of Villamaría and Manizales (State of Caldas) throughout the year.

3.2. Total Polyphenol Content (TPC) and Total Flavonoid Content (TFC)

Polyphenols were extracted from the fresh pulp of white Colombian yacón for 24 and 144-hour periods. Solvents acquired different colors (from colorless to light yellow) a few hours into the extraction process.

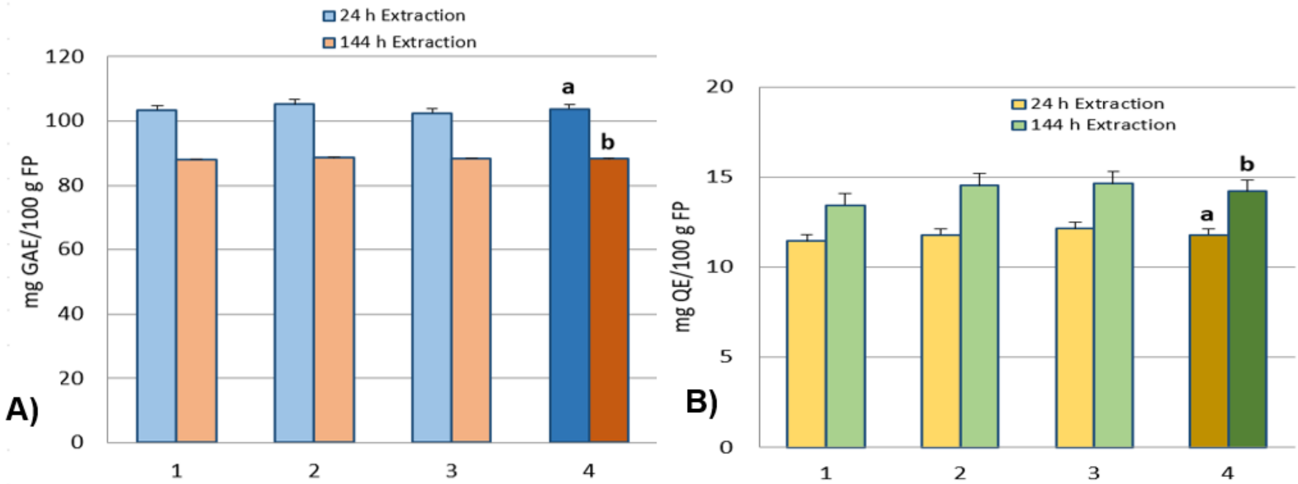

Figure 3.
A) Total polyphenol content (TPC), and **B)** Total flavonoid content (TFC) in yacón extracts (24 and 144-hour-long extractions). Dark bars show means and standard deviation (+/- SD) for triplicate reactions. Lower case letters represent statistical significance based on the T-Student´s test and a *p-value* < 0.05.

As shown in Figure 3 A**)**, TPC in fresh white yacón, for the 24 h extraction, was higher by less than 20% in comparison to the prolonged (144 h) extraction, with significant differences in the assay. On the other hand, TFC (Figure 3 B**)** was higher in the 144 h extraction. The approximate ratio for both groups of phenolic compounds (TPC: TFC) was around 9:1 for the 24 h extraction and 6:1 for the prolonged extraction (144 h). A longer extraction time favored more detection of flavonoids.

3.3. DPPH Assay for Radical Scavenging - Antioxidant Activity

Added antioxidant activity for yacón extracts (24 and 144 h short and prolonged extractions) yielded about 20% of inhibitory concentration (IC 50%), as shown in Figure 4. The shorter extraction process captures more phenolic compounds, including small phenolic acids, and coincides with higher total polyphenol content for the same extraction group. For the prolonged extraction process (144 h), the antioxidant potential declined by less than 2%.

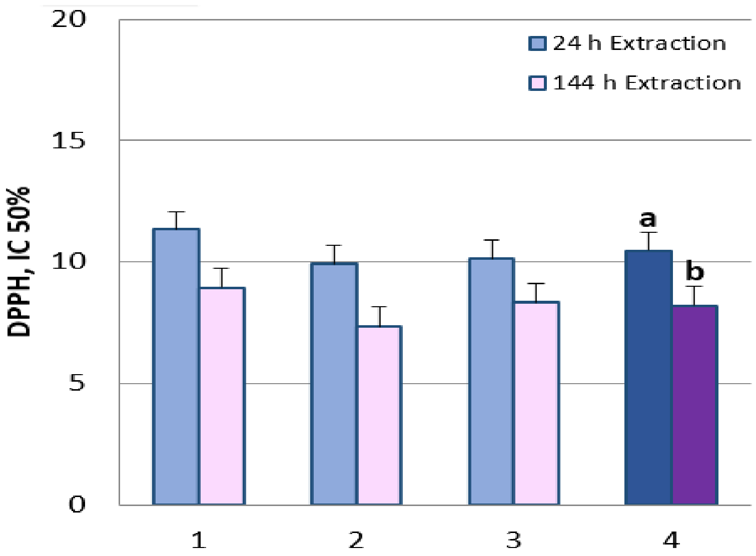

Figure 4.
Antioxidant activity, based on DPPH, from white yacón (24 and 144 h extractions). Darker colored-bars show means and standard deviation (+/- SD) for triplicate reactions. Different lowercase letters represent statistical significance based on the T-Student test and a *p-value* < 0.05.

Antioxidant activity, with respect to the content of total polyphenols and total flavonoids, relates more to the latter group. As displayed in Figure 5 there are close values, in proportions or percentages, for TFC with DPPH activity in the extracts. The relation TFC: DPPH shows a close ratio (an approximate proportion of 1:1). On the other hand, with respect to TPC with DPPH activity, the proportion can be as high as 4:1. These results show an important proportion of polyphenols in Colombian white yacón that can be evaluated for other potential biological activities different from the described antioxidant property.

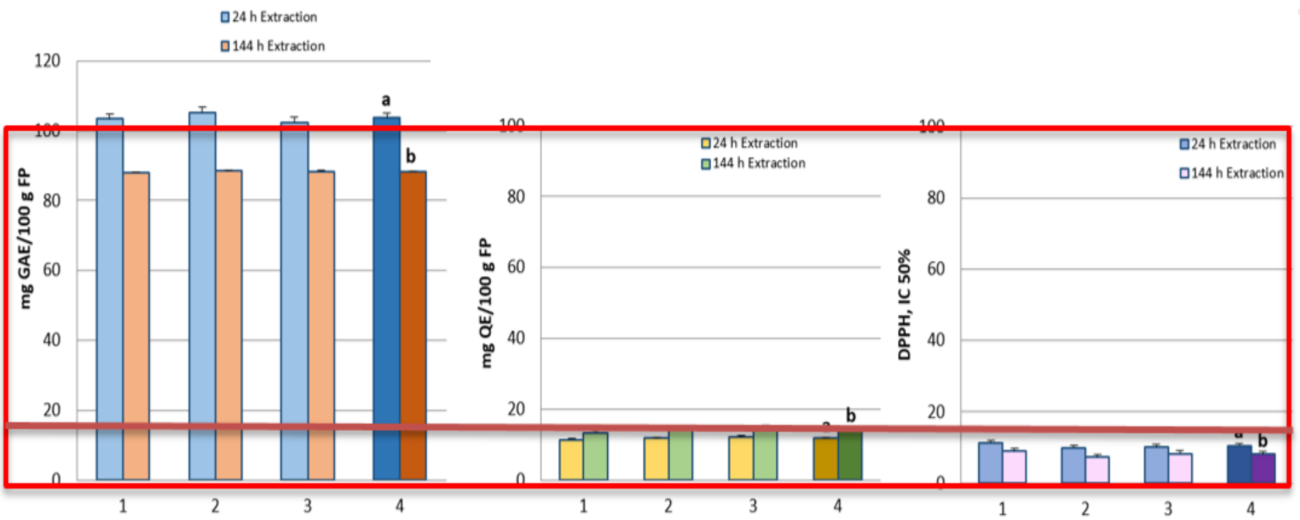

Figure 5.
Comparative proportion of polyphenols and flavonoids with their antioxidant activity in white yacón extracts (24 and 144-hour-long extractions).

Approximately 80% of the total phenolic content in the extracts (24 and 144-hour long extractions) can be tested for possible anti-inflammatory, anti-glycemic, and anti-lipidemic activities, once it is observed that close to 20% of TPC acts as antioxidant agents in white yacón. Over 144 hours, there is still antioxidant potential along with the presence of more polyphenols with potential benefits such as anti-inflammatory effects, beneficial for digestive health.

4. Discussion

Studies reveal that yacón consumption leads to a constant and sustained contribution of FOS and antioxidant benefits, with possible effects against metabolic diseases [8-10]. Slow fructose metabolism contributes to stable glucose concentrations and leads to managing fasting time without compromising cell metabolic function [8, 9]. The hypolipidemic effects, generated through the production of SCFA by the intestinal microbiota, inhibit lipolysis, increase the mobilization of triglycerides, and promote adipogenic differentiation, thereby reducing the risk of associated atherothrombotic or cardiovascular diseases [6, 10]. FOS in yacón offers benefits to the digestive system due to its slow and prolonged availability. The FOS digestive process reaches maximum absorption by day 7, while accessibility continues up to 12 days, reaching its lowest concentration [20].

In the present study, a short (1 day) and a prolonged (6 days) extraction of polyphenols and flavonoids provided a connection to antioxidant properties. Figueira [21] highlights the benefit of FOS extracted naturally from the roots compared to synthetic contributions and how they can be used in daily functioning in a morbid digestive system [22]. The prolongation of carbohydrate degradation through the inhibition of α-amylase and α-glucosidase manages to decrease blood glucose excretion levels in diabetic patients, deterring metabolic syndrome progression due to yacón consumption [22].

The slow extraction procedure and slow absorption process (connected to the digestive process) evidence an extended contribution of polyphenols with respect to their flavonoid concentration and antioxidant activity [23]. The present results tested short and extended extractions for total polyphenol, total flavonoid content, and antioxidant characteristics after 24 and 144 hours, a review on the hypoglycemic property of yacón by Contreras-Puentes and Alvíz-Amador [23] agrees on the cytoprotective capacity conferred by polyphenols and FOS associated with repetitive ingestion of yacón [23]. The prolonged extraction period (6 days) favored increased detection of flavonoids. This could be due to the high FOS content in yacón, and the fact that polyphenols and flavonoids are typically linked to glycoside rings, forming more complex and voluminous chemical structures.

A study in Germany comparing seven different yacón cultivars (Cajamarca, Cusco, Early White, Late Red, Morado, New Zealand, and Quinaut) resulted in variable ratios for polyphenols and flavonoids, in some cases higher values for TFC, considering that flavonoid content must be contained in the TPC results [24]. Quantitation (ratios) of polyphenols and flavonoids is necessary to predict and determine effective biological activity in different aspects. Chessum et al. [25] tested three different batches of yacón from New Zealand to determine phenolic concentration and antioxidant activity related to FOS content [25]**.** In agreement with the results of the present study, TPC, in proportion to biological activity and FOS content, shows that part of the polyphenol content acts directly in a specific function, leaving extra content available for other possible functionalities [25]. High TPC content does not always correlate directly and positively with antioxidant activity, but it indicates the presence of phenolics that are available for other biological activities. Figure 3 B shows that TFC in Colombian white yacón accounts for active flavonoids that contribute to antioxidant activity, directly proportional to as seen in Figure 5. After 6 days of extraction, DPPH activity has declined by less than 20%, and the present results show that there is a similar ratio for flavonoid content and antioxidant activity in both short and prolonged extraction.

Approximately 80% of the total phenolics in the extracts (24 and 144 hour extractions) can be tested for possible anti-inflammatory, anti-glycemic, and anti-lipidemic activities, once it is observed that close to 20% of TPC acts as antioxidant agents in Colombian white yacón. Phenolics in yacón, such as caffeic and ferulic acids, found in other varieties and other natural products, display multiple effects and benefits to human health [19, 25-28]. The role of the intestinal microbiota, aiming for optimal microenvironments to avoid the progression of diseases and to achieve a pro- and anti-inflammatory balance, is related to the development of pathologies of metabolic, intestinal, and even psychological nature [6].

Phytochemical capacity reduces not only the progression of diabetes mellitus but also the anti-inflammatory phenomena associated with metabolic diseases [23, 28, 29]. Given the potential benefit of modifying the intestinal microbiota, the metabolic and intestinal responses to stressful events in people who received diets based on yacón as carbohydrates resulted in high beneficial concentrations of succinic, lactic, acetic, and propionic acids, as well as fecal mucin [24, 25]. Although research has provided pillars in the etiology of CRC, environmental factors have perpetuated an anchor in the treatment capable of specifically directing management targets [30].

5. Conclusion

More *in vitro* and *in vivo* assays, to determine the efficacy of polyphenols and antioxidant flavonoids in natural products of easy access and prolonged antioxidant effects, are needed. Fruits and vegetables with high polyphenol and FOS content should be included in regular diets for all ages. Human consumption of pro-inflammatory foods aggravates the therapeutic landscape in modern times. Nutritional education projects and work should be oriented from undergraduate health sciences courses for future professionals in different fields; this strategy could be useful to accompany therapeutic decisions in their future medical assistantship and work.

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