

Impact of simulated in vitro gastrointestinal digestion on the antioxidant activity and phenolic compounds of soursop peel (*Annona muricata* L.).

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Abstract

This work aimed to investigate *in vitro* phenolics bioaccessibility and soursop peel's antioxidant activity. Proximate composition, ascorbic acid, total phenolic compounds, and *in vitro* antioxidant activity (DPPH, ABTS, and FRAP assays) were conducted on soursop peel and pulp. The accessibility of total phenolics and antioxidant capacity of soursop peel and pulp was assessed through simulated *in vitro* digestion. Soursop peel had a significant amount of fiber, particularly insoluble fiber, and higher levels of total phenolic compounds and antioxidant capacity than pulp. The pulp has 30% higher levels of ascorbic acid than the peel. Simulated *in vitro* digestion, the total phenolic compounds of the peel exhibited stability throughout the gastric and intestinal stages. In the pulp, there was an increase in total phenolic compounds that persisted until the final stage. After the simulation of *in vitro* digestion, the peel showed stability in DPPH antioxidant capacity analysis and obtained higher accessibility in the enteric II stages (40% and 29%) on ABTS and FRAP assays. Soursop pulp increased accessibility in the gastric stage on DPPH and FRAP assay. In the ABTS method of antioxidant capacity evaluation, the pulp showed the highest values in enteric phase II. These results are essential for human nutrition as they provide information about soursop peel and pulp's nutritional and bioactive composition. Furthermore, the *in vitro* accessibility of these compounds offers insights into their potential utilization by the organism. This knowledge holds significant implications for nutrition experts, as it can inform the development of healthier dietary habits and promote enhanced health outcomes.

1. Introduction

Soursop fruit (*Annona muricata* L.), also known as Graviola, is a member of the *Anonaceae* family and is found in Central and South America, Africa, Asia, and Australia [1, 2]. It was introduced to Brazil by the Portuguese in the 14th century and is primarily grown in the warm and semi-arid regions of the Northeast [3]. The state of Bahia is the largest producer in Brazil, followed by Pernambuco and Alagoas, with a harvested area of 2.760 hectares and revenues of R\$ 24.323.000 million in 2017 [4].

Soursop has been recently highlighted in national and international commerce due to the studies on its biological effects and consequently the impact of its consumption on human health [5, 6, 7]. The scientific community widely exploits the pulp and leaf of the soursop [8, 9, 6] about their anti-carcinogenic potential.

The fruit is known for its conical shape and comprises pulp, peel, and seeds. The peel is characterized by a dark-green color and the appearance of rigid spines, while the pulp presents a whitish color and soft consistency after maturing. The pulp, generally used to make juices, jams, ice cream, and sweets, has a sweet or sub-acidic taste. The peel comprises much of the fruit's weight and is often discarded or underused for animal feed [10]. However, although the soursop's peel corresponds to a large percentage of the fruit's weight, there are not enough data on the proximate composition and functional composition of the soursop peel, which justifies the development of the present study.

Fruit by-products, such as peels and seeds, have mostly bioactive compounds and nutritional value with beneficial effects on human health superior to those demonstrated by the edible parts [11, 12, 13, 8].

Knowledge of the proximate composition and consequent valorization of fruit by-products can contribute to sustainable development, demonstrating this research's economic, environmental, social, and technological impact.

Therefore, it is essential not only to identify the bioactive compounds but also to investigate the effects of the digestive process on phenolics and antioxidant activity. This is because factors such as pH and enzymes used during gastrointestinal digestion can modify the active substances in the food [14, 15]. Moreover, the accessibility of certain phenolic compounds is modulated by the presence of specific nutrients, such as fiber, which can have a positively or negatively impact on their accessibility [16, 17]. The potential impact of the digestion process on the effective biological action of bioactive compounds in soursop peel has yet to be extensively studied in the scientific community [18, 19].

This study aims to investigate the impact of *in vitro* digestion on soursop peel's antioxidant activity and phenolic compounds. The bioaccessibility of phenolic compounds will be assessed, as it is essential to understand the potential reuse of discarded fruit parts comprehensively.

2. Material and methods

The material and methods section are provided as supplementary materials.

3. Results and Discussion

3.1 Sample analysis

Table 1 presents the proximal composition of the soursop peel and pulp, which were analyzed for moisture, digestible carbohydrates, proteins, lipids, ash, and dietary fiber (soluble and insoluble). The fruits analyzed had an average weight of 2.3 kg, with 70.4% of the total weight corresponding to the pulp, 22.5% to the peel, and 7.1% to the seed.

Table 1 - Results are expressed in percentage (%). *1: Calculated by difference (100 – (moisture + ashes + lipids + protein + total dietary fiber)). *2: Total carbohydrate – total dietary fiber. Different lowercase letters in the row indicate differences by t-test ($p < 0,05$). Values are mean $\pm$ standard deviation. Identical lowercase letters in the same row indicate no difference in the t-test ($p < 0,05$).

The results indicated that both parts of the soursop were high in moisture and dietary fiber but had lower concentrations of protein, lipids, and ash (Table 1). The peel was found to have a higher caloric value than the pulp, which could be attributed to its higher lipids content ($p < 0.05$).

No significant difference ($p < 0.05$) was found in the total carbohydrate between the two parts. The digestible carbohydrate content was higher in the pulp (90%) than in the peel due to the latter's high fiber content. These findings have important implications for the caloric value and potential uses of the two parts of soursop fruit.

Soursop peel presents a significant amount of dietary fiber (59%) compared to the pulp, making it a promising functional ingredient that requires consuming 137 g/day of pulp or 57 g/day of fruit peel. In addition to its health benefits, using the inedible parts of the fruit could help to reduce the environmental impact [11, 12]. In the present study, the peel has the highest content of insoluble fiber (67%), which can aid in promoting a healthy gastrointestinal tract and increasing feelings of fullness [20]. Many studies are being conducted to explore the nutritional value of fruit by-products. These results suggest that soursop peel could be incorporated into new food products as flour to add nutritionally and meet the growing demand for fiber-rich foods in the food industry, ultimately leading to a positive economic impact [21, 22, 23, 24].

Table 2 shows that the soursop pulp fruit contains 29% more ascorbic acid than the peel ($p < 0,05$). Previous studies also reported high ascorbic acid levels in the *Anonaceae* family's fruits, including soursop [25, 26]. This high ascorbic acid content may be attributed to the fruit's strong antioxidant capacity, which helps reduce the production of free radicals [26].

Table 2 - Values are mean $\pm$ standard deviation. Identical lowercase letters in the same row indicate no difference between them in the t-test ($p < 0,05$).

Table 2 displays the assessment outcomes conducted to determine the antioxidant capacity and total phenolic compounds of the soursop pulp and peel extracts. The results indicated that the soursop peel extract contained more significant phenolic compounds than the pulp extract. Regarding antioxidant capacity, the peel and pulp extracts exhibited noticeable differences when evaluated using ABTS and DPPH methods but not when measured by the FRAP technique (Table 2).

Results indicated that peel and pulp presented explicit contents of total phenolic compounds, and peel showed a 17% higher content of phenolic compounds than the pulp (Table 2). A higher amount of phenolic compounds in the peel can be explained by the fact that this part of the fruit is more susceptible to environmental stress factors and participate in plant defense mechanisms, such as attack by insects, UV radiation, and temperature. Thus, the phenolic compounds may be generated from the secondary metabolism of the plant [27].

Table 3 - Values are mean $\pm$ standard deviation. Identical lowercase letters in the same row indicate no difference between them in the t-test ($p < 0,05$).

In this study, five phenolic compounds were detected in peel and pulp of soursop, were gallic acid, benzoic acid, coumaric acid, ferulic acid and hesperidin, predominating phenolic acids characterized by HPLC-DAD (Table 3). The phenolic acids are the main phenolic compounds of soursop, according to the literature. The peel showed a 72% higher content of hesperidin than the pulp. In other studies, expressive values of phenolic compounds with antioxidant capacity were also found in fruit peels in *Annonas* [28, 27].

This study showed a valorization of the by-product in the cosmetic, pharmaceutical, and food industries, being important information for the non-waste of non-edible parts of food. The *in vitro* antioxidant capacity

methods performed in this study serve as an initial tool, as they are low-cost and high-yielding and can help identify these compounds for later *in vivo* assays.

3.2 Effects of digestion *in vitro* on TPC

The changes of TPC in soursop peel and pulp during simulated *in vitro* digestion are shown in Fig. 1. After simulated digestion, the TPC in peel and pulp shows different trends. They were considering the results obtained in evaluating the accessibility of total phenolic compounds of soursop. The results of the total phenolic compounds present in the pulp subjected to simulated *in vitro* digestion showed that the phenolic compounds were constant in the gastric digestion stage and then increased significantly in the intestinal digestion stage.

For the peel, there is no difference between the gastric and enteric phases of *in vitro* digestion, as shown in Fig. 1.

Figure 1 – Total phenolic compound content (TPC) of pulp (A) and peel (B) of soursop submitted to the gastric, enteric phase I, and enteric phase II of *in vitro* simulated digestion. EG: Gastric phase, EEI: Enteric phase I, EEII: Enteric phase II. NS = not significant ($p < 0,05$); *** = significant differences ($p < 0,05$). Compared to the Tukey test at 5% probability.

After investigating the effect of *in vitro* digestion on the phenolic compounds in soursop pulp, there was a 12% increase in accessibility from gastric to enteric phase II and 9% from enteric phase I to enteric phase II. The peel obtained stability between the analyzed phases.

The results were positive, showing good association with the release of total phenolic compounds in the last stage of digestion, thus generating possible impact on human health and showing that the peel is a good product for potential biological effects on the gastrointestinal tract. In the action of proteases, polysaccharides, and peptides, among other nutrients, the total phenolic compounds are released, thus binding with proteins, justifying their increased accessibility of total phenolic compounds [14, 29].

Similar results were found for soursop pulp in the study by Blancas-Benítez et al. [30], where the highest release occurred in the intestinal phase of the *in vitro* assay. During intestinal digestion, enzymes such as hydrolases, responsible for the hydrolysis of carbohydrates, can react and interact between carbohydrates and compounds, resulting in increased accessibility in the gastrointestinal tract [31]. Furthermore, phytochemicals such as gallic acid (83.5%), chlorogenic acid (6.4%), and caffeic acid (10.1%) are potentially absorbed in the intestinal phase [30].

Some studies have evaluated the accessibility of fruit by-products and their inedible parts, such as the peels, where they showed positive accessibility of total phenolic compounds, showing to be a promising ingredient for the food industry and possible insertion in new healthy products [32, 17]. Depending on the food and its connection to the food matrix, as well as the nutrients of the food, can affect the release of phenolic acids in the intestine [14]. It is worth pointing out that the content of active substances in the food may be reduced due to the pH employed in enteric phases I and II during *in vitro* intestinal digestion and the interaction between the enzyme's bile and pancreatin with the analyzed fruit [15].

Ferreyra et al. [17] studied fruit by-products, where they found increased accessibility between the oral, gastric, and intestinal phases, showing that they were stable and demonstrating their potential accessibility. Some total phenolic compounds may remain unchanged, and others may change their chemical structure, related to the pH changes in the simulation phases of the *in vitro* digestion [33].

The total phenolic compounds can be bound to proteins in various ways, such as through hydrogen, covalent and hydrophobic bonds, thus justifying their more significant release in the intestinal phase [29, 34].

The accessibility of some phenolic compounds is internally linked to some nutrients, such as fiber, minerals, proteins, carbohydrates, and lipids, and can negatively alter their accessibility, as it happened in the gastric phase [16, 17]. On the other hand, the low pH with the action of the pepsin enzyme in the gastric phase releases phenolic compounds, which bind to carbohydrates [35]. Covalent and non-covalent bonds connect polyphenols and dietary fiber. Some factors, such as ionic strength, temperature, polyphenols, and fiber structure, affect their release [14].

For example, dietary fiber may decrease the accessibility of phenolic compounds in the gastrointestinal tract [36]. The low accessibility in the gastric stage may be related to the presence of soluble fibers, such as pectin, in the soursop pulp and peel, presenting gelation and thus being able to interact with the bioactive compounds, inhibiting their release in the gastrointestinal tract [29, 37]. In addition, some anti-nutritional compounds, such as the phytochemicals saponin, alkaloids, and tannins, present in soursop pulp and peel, can also negatively alter its accessibility [38].

In this study, the stability of accessibility of phenolic compounds to the rind and increase between gastric and enteric phase II was observed. However further studies using high-performance liquid chromatography (HPLC) are needed to identify the individual phenolic compounds after digestion and better understand and justify the decrease, increase or stability of these compounds during the digestive process.

3.2 Effects of simulated digestion on antioxidant capacity

There was stability for the peel between the gastric, enteric I, and enteric II phases in the antioxidant capacity DPPH. There was a significant difference between the first and last phases for the antioxidant capacity ABTS. From the above results, we can conclude that the antioxidant activity of soursop peel and pulp measured by the FRAP method showed a similar trend during the simulated digestion *in vitro*, as there increased after gastric digestion and decreased during intestinal digestion.

Figure 2 – Content antioxidant capacity (DPPH, ABTS e FRAP) of pulp (A) and peel (B) of soursop submitted to the gastric, enteric phase I, and enteric phase II of *in vitro* simulated digestion. EG: Gastric phase, EEI: Enteric phase I, EEII: Enteric phase II. NS = not significant ($p < 0,05$); *** = significant differences ($p < 0,05$). Compared to the Tukey test at 5% probability.

These methods were employed to evaluate the changes in antioxidant activity during simulated *in vitro* digestion. In DPPH analysis, there was stability for the peel in all three phases of digestion. However, a decline can still be seen for the pulp accessibility at 4% from gastric to enteric phase I and stability between

enteric phase I and II. The reduction from the gastric to the enteric phase in the pulp may be due to the composition of the active metabolites of the fruit by the gut microbiota [39].

In the ABTS analysis, there was a significant change between the three phases for the pulp, increasing from the gastric phase to enteric phase II considerably by 57%, showing a higher antioxidant capacity. In comparison, for the peel, the first two phases remained stable, and a 40% increase in accessibility between enteric phase I and II. Many polyphenols are released in the gastric phase because, during intestinal digestion at neutral or weakly alkaline pH, most compounds are lost by incubation with bile and pancreatic salts. For this reason, the phenolic compounds are degraded or converted to new compounds. Another answer to the low antioxidant capacity in the gastric stage is because of its short duration of contact with enzymes in the stomach. The increase in antioxidant activity between the stages also occurs by the change from acidic pH to basic pH, thus the release of phenolic compounds, and this occurs because there is deprotonation of the hydroxyl group on the aromatic ring. Still, of all the assays, the most suitable for assessing digestion in the gut is the ABTS method due to its pH of 7–7.5 [14].

Sollano-Mendieta et al. [40], when analyzing the antioxidant capacity in the *in vitro* digestion of fruits, obtained expressive results in ABTS and DPPH analysis in the *in vitro* intestinal digestion phase, which the pH variation in the enteric phase digestion can explain. Studies have reported that the transition from acidic to alkaline pH can increase the release of total phenolic compounds and flavonoids, thus contributing to the increase of antioxidant capacity, occurring by deprotonation of hydroxyl groups that are present in the aromatic rings [41, 42].

In the FRAP analysis, there was stability in both parts analyzed between the gastric and enteric phase II, and in both decline between the gastric and enteric phase I, being pulp with 26% and peel with 15%. Other studies performed with fruit by-products have shown similar results [43]. This reduction may be related to the pH changes in the *in vitro* digestion simulation phases [33].

The properties of these functional components *in vitro* are related to their accessibility after food consumption. They are affected by several factors, such as the extent to which they are released from the food matrix in the gastrointestinal tract, their digestive stabilities, and their metabolism in the human body [18, 44]. The stability of these phytochemicals is related to interfering environmental factors during human digestion, such as pH, digestive enzymes, and temperature [18, 19, 40].

Although all the antioxidant activity quantification methods are direct (DPPH, ABTS, and FRAP), there was a difference between the values found in each method because each method has its particularities and evaluates the antioxidant capacity in different ways.

4. Conclusion

Soursop peel has expressive dietary fiber values, indicating that its flour can be a promising food in the composition of new foods in the food industry. As for the antioxidant capacity and content of total phenolic compounds, the peel obtained the highest values, demonstrating its potential to be explored as a functional ingredient. Simulated digestion results for TPC and antioxidant capacity demonstrated the stability of the

bioactive antioxidant compounds until the end of the assay, thus demonstrating their potential beneficial effect on human health.

Declarations

Author contributions Conceptualization: YOD and MCM; Investigation: YOD, MCM, GAL, FLO, TRS and BS; Writing – original draft: YOD and MCM; Writing – review and editing: YOD and MCM; Supervising: MCM.

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Data Availability Data and material may be provided on request by the corresponding authors.

Ethical Approval Not applicable.

Conflict of Interest The authors declare no conflict of interest.

References

1. GBIF. Annonaceae in GBIF Secretariat (2021) Checklist Dataset. IOP Publishing GBIF <https://GBIFBackboneTaxonomy>. Accessed 21 Nov 2022
2. Fuentes LMH, Gonzalez EM, Magana MLG et al (2022) Current situation and perspectives of fruit *Annonaceae* in Mexico: biological and agronomic importance and bioactive Properties. Plants, p 11
3. Pinto ACQ, Da Silva EM (1995) A cultura da graviola. Brasília: Embrapa-SPI. 106P; 16 cm – (Coleção Plantar, 31)
4. Soares LGA, Fernandes TFS, De Oliveira ASB (2023) Panorama nacional da produção de graviola. IOP Publishing [http://Panoramanacionaldaproduçãodegraviola|RevistaCampo&Negócios\(revistacampoenegocios.com.br\)](http://Panoramanacionaldaproduçãodegraviola|RevistaCampo&Negócios(revistacampoenegocios.com.br)). Accessed 28 Jan 2023
5. Ilango S, Sahoo DK, Paital B et al (2022) A review on *Annona muricata* and its anticancer activity. Cancers 14:4539
6. Mutakin M, Fauziati R, Fadhilah FN et al (2022) Pharmacological activities of soursop (*Annona muricata* Lin). Molecules 27:1201
7. Neta LMTS, Jesus MS, Da Silva JLA et al (2019) Effect of spray drying on bioactive and volatile compounds in soursop (*Annona muricata*) fruit pulp. Food Res Int 124:70–77
8. Wahab SMA, Jantan I, Haque MA et al (2018) Exploring the leaves of *Annona muricata* L. as a source of potential anti-inflammatory and anticâncer agents. Front Pharmacol 9:661
9. Balderrama-Carmona AP, Silva-Beltrán NP, Gálvez-Ruiz JC et al (2020) Antiviral, antioxidant and antihemolytic effect of *Annona muricata* L. leaves extracts. Plants, 9:1650, 2020
10. Damiani C, MARTINS GAD, BECKER FS (2023) Aproveitamento de resíduos vegetais: potenciais e limitações. IOP Publishing Files https://files.cercomp.ufg.br/weby/up/396/o/Livro_Aproveitamento_de_Res%C3%ADduos_Vegetais.pdf Accessed 26 Jan 2023

11. Campos DA, Gómez-García R, Vilas-Boas AA et al (2020) Management of fruit industrial by-products – A case study on circular economy approach. *Molecules* 25:320
12. De Oliveira FL, Arruda TYP, Morzelle MC et al (2022) Fruit by-products as potential prebiotics and promising functional ingredients to produce fermented milk. *Food Res Int* 161:111841
13. Gajalakshmi S, Vijayalakshmi S, Devi RV (2012) Phytochemical and pharmacological properties of *Annona muricata*: a review. *Int J Phar Sci* 4:3–6
14. Luo X, Tian M, Cheng Y et al (2022) Effects of simulated *in vitro* gastrointestinal digestion on antioxidant activities and potential bioaccessibility of phenolic compounds from *K. coccinea* fruits. *Front Nut* 9:1024651
15. Alminger M, Aura AM, Bohn T et al (2014) *In vitro* models for studying secondary plant metabolite digestion and bioaccessibility. *Compr Reviews Food Sci Food Saf* 13:413–436
16. Guemede HF, Ratta N (2014) Antinutritional factors in plant foods: potential health benefits and adverse effects. *Int J of Nut Food Sci* 3:284–289
17. Ferreyra S, Torres-Palazzolo CT, Bottini R et al (2021) Assessment of *in vitro* bioaccessibility and antioxidant capacity of phenolics compounds extracts recovered from grapevine bunch stem and cane by-products. *Food Chem* 348:129063
18. Zheng G, Deng J, Wen L, You L et al (2018) Release of phenolic compounds and antioxidant capacity of Chinese hawthorn *Crataegus pinnatifida* during *in vitro* digestion. *J Func Foods* 40:76–85
19. Dou Z, Chen C, Huang Q et al (2022) *In vitro* digestion of the whole blackberry fruit: bioaccessibility, bioactive variation of active ingredients and impacts on human gut microbiota. *Food Chem* 370:e131001
20. CUPPARI L (2014) Guias de medicina ambulatorial e hospitalar da EPM-UNIFESP. Manole, São Paulo
21. Lebaka VR, Wee YJ, Ye W et al (2021) Nutritional composition and bioactive compounds in three different parts of mango fruit. *Int J Environ Res Public Health* 18:741
22. Othman S, Anibarro-Ortega M, Dias MI et al (2022) Valorization of quince peel into functional food ingredients: a path towards zero waste and sustainable food systems. *Heliyon* 8:11042
23. Lasano NF, Hamid AH, Karim R et al (2019) Nutritional composition, anti-diabetic properties and identification of active compounds using UHPLC-ESI-Orbitrap-MS/MS in *Mangifera odorata* L. peel and seed kernel. *Molecules* 24:320
24. Popova V, Petkova Z, Mazova N et al (2022) Chemical composition assessment of structural parts (seeds, peel, pulp) of *physalis alkengi* L. fruits. *Molecules* 27:5787
25. Dos Santos WLN, Sauthier MCS, Cavalcante DD et al (2016) Mineral composition, nutritional properties, total phenolics, and flavonoids compounds of the atemoya fruit (*Annona squamosa* L. x *Annona cherimola* Mill.) and evaluation using multivariate analysis techniques. *An Braz Acad Sci* 88:1243–1252
26. Leite DOD, Camilo CJ, Nonato CFA et al (2021) Chemical profile and evaluation of the antioxidant and anti-acetylcholinesterase activities of *Annona squamosa* L. (*Annonaceae*) extracts. *Foods*, 10:2343

27. Prado LG, Arruda HS, Araújo NMP et al (2020) Antioxidant, antiproliferative and healing Properties of araticum (*Annona crassiflora* Mart.) peel and seed. Food Res Int 133:109168
28. Rojas-Garcia A, Rodriguez L, Cádiz-Gurrea MLC et al (2022) Determination of the bioactive effect of custard apple by-products by *in vitro* assays. Int J Mol Sci 23:9238
29. Padayachee A, Netzel G, Netzel M et al (2012) Binding of polyphenols to plant cell wall analogs – Part 2: Phenolic acids. Food Chem 135:2287–2292
30. Blanca-Benitez FJ, Montalvo-Gonzalez E, González-Aguilar GA et al (2019) *In vitro* bioaccessibility and release kinetics of phenolic compounds from guava (*Psidium guajava* L.) and soursop (*Annona muricata* L.) pulp. Revista Especializada em Ciências Químico-Biológicas, 22:1–7
31. González-Aguilar GA, Blancas-Benitez FJ, Sayago-Ayerdi SG (2017) Polyphenols associated with dietary fibers in plant. Food Sci 13:84–88
32. Gomez-Lopez I, Lobo-Rodrigo G, Portillo MP et al (2021) Characterization, stability, and bioaccessibility of betalain and phenolic compounds from *Opuntia stricta* var. *Dilleni* fruits and products of their industrialization. Foods 10:1593
33. Gutiérrez-Grijalva EP, Antunes-Ricardo M, Acosta-Estrada BA et al (2019) Cellular antioxidant activity and *in vitro* inhibition of alfa-glucosidase, alfa-amylase and pancreatic lipase of orégano polyphenols under simulated gastrointestinal digestion. Food Res Int 116:676–686
34. Bouayed J, Hoffmann L, Bohn T (2011) Total phenolics, flavonoids, anthocyanins, and antioxidant activity following simulated gastro-intestinal digestion and dialysis of apple varieties: bioaccessibility and potential uptake. Food Chem 128:14–21
35. Xiao J (2017) Dietary flavonoid aglycones and their glycosides: which show better biological significance? Crit Reviews Food Sci Nut 57:1874–1905
36. Jakobek L, Matic P (2019) Non-covalent dietary fiber - Polyphenol interactions and their influence on polyphenol bioaccessibility. Trends Food Sci & Tech 83:235–247
37. Mosele JI, Macia A, Romero MP et al (2016) Stability and metabolism of Arbutus unedo bioactive compounds (phenolics and antioxidants) under *in vitro* digestion and colonic fermentation. Food Chem 201:120–130
38. Agu KC, Okolie PN (2017) Proximate composition, phytochemical analysis, and in vitro antioxidant potentials of extracts of *Annona muricata* (Soursop). Food Sci Nut 5:1029–1036
39. Barak TH, Celep E, Inan Y et al (2019) Influence of *in vitro* human digestion on the bioavailability of phenolic content and antioxidant activity of *viburnum opulus* L. (European cranberry) fruit extracts. Ind Cr & Prod 131:62–69
40. Sollano-Mendieta XC, Meza-Marquez OG, Osorio-Revilla G et al (2021) Effect of *in vitro* digestion on the antioxidant compounds and antioxidant capacity of 12 plum (*Spondias purpurea* L.) ecotypes. Foods 10:1995
41. Dutra RLT, Dantas AM, Marques DA et al (2017) Bioaccessibility and antioxidant activity of phenolic compounds in frozen pulps of Brazilian exotic fruits exposed to simulated gastrointestinal conditions. Food Res Int 100:650–657

42. Dantas AM, Mafaldo IM, Oliveira PML et al (2019) Bioaccessibility of phenolic compounds in native and exotic frozen pulps explored in Brazil using a digestion model coupled with a simulated intestinal barrier. Food Chem 274:202–214
43. Lucas-González R, Viuda-Martos M, Álvarez JA et al (2018) Changes in bioaccessibility, polyphenol profile and antioxidant potential of flours obtained from persimmon fruit (*diospyros kaki*) co-products during *in vitro* gastrointestinal digestion. Food Chem 256:252–258
44. Dou Z, Chen C, Fu X (2019) Bioaccessibility, antioxidant activity and modulation effect on the gut microbiota of bioactive compounds from *Moringa oleifera* Lam. leaves during digestion and fermentation *in vitro*. Food Func

Tables

Table 1 – Proximate composition (% w/w) of Soursop pulp and peel (mean $\pm$ Standard deviation).

	Peel	Pulp
Energetic Value (kcal 100 g ⁻¹)	97,97	72,30
Moisture	76,44 $\pm$ 1,86	81,41 $\pm$ 0,58
Total Carbohydrate	18,62	16,41
Digestible carbohydrate	0,94	9,09
Total dietary fiber	17,68	7,32
Insoluble fiber	16,67 $\pm$ 1,41	5,40 $\pm$ 0,97
Soluble fiber	1,01 $\pm$ 1,38	1,76 $\pm$ 0,36
Protein	1,75 $\pm$ 0,10	1,43 $\pm$ 0,06
Lipids	2,25 $\pm$ 0,07	0,10 $\pm$ 0,00
Ash	0,94 $\pm$ 0,03	0,64 $\pm$ 0,05

Results are expressed in percentage (%). *¹: Calculated by difference (100 – (moisture + ashes + lipids + protein + total dietary fiber)). *²: Total carbohydrate – total dietary fiber. Different lowercase letters in the row indicate differences by t-test ($p < 0,05$). Values are mean $\pm$ standard deviation. Identical lowercase letters in the same row indicate no difference in the t-test ($p < 0,05$).

Table 2 – Total phenolic compound content (μg EAG 100 g⁻¹), *in vitro* antioxidant capacity by DPPH (μM ET g⁻¹), ABTS (μM ET g⁻¹), FRAP (μM ferrous sulfate g⁻¹) and Ascorbic acid (mg ascorbic acid 100 g⁻¹) methods of soursop peel and pulp extracts.

	Peel	Pulp
TFC	645 ± 54	532 ± 18
DPPH	3280 ± 158	2330 ± 134
ABTS	5768 ± 386	4401 ± 133
FRAP	8997 ± 886	7727 ± 649
Ascorbic acid	40,2 ± 0,9	56,4 ± 3,8

Values are mean ± standard deviation. Identical lowercase letters in the same row indicate no difference between them in the t-test (p<0,05).

Table 3 – Content of phenolic compounds of the peel and pulp extracts.

	Peel	Pulp
Galic acid	44,26 ± 0,47	43,70 ± 0,25
Benzoic acid	21,51 ± 0,33	20,09 ± 0,59
Coumaric acid	30,65 ± 1,22	27,66 ± 0,40
Ferulic acid	Traces	17,09 ± 0,55
3,4 Dihydroxibenzoic	n.d	16,51 ± 2,08
Abscisic acid	7,38 ± 1,61	n.d
Hesperidin	61,08 ± 6,17	17,02 ± 0,91

Values are mean ± standard deviation. Identical lowercase letters in the same row indicate no difference between them in the t-test (p<0,05).

Figures

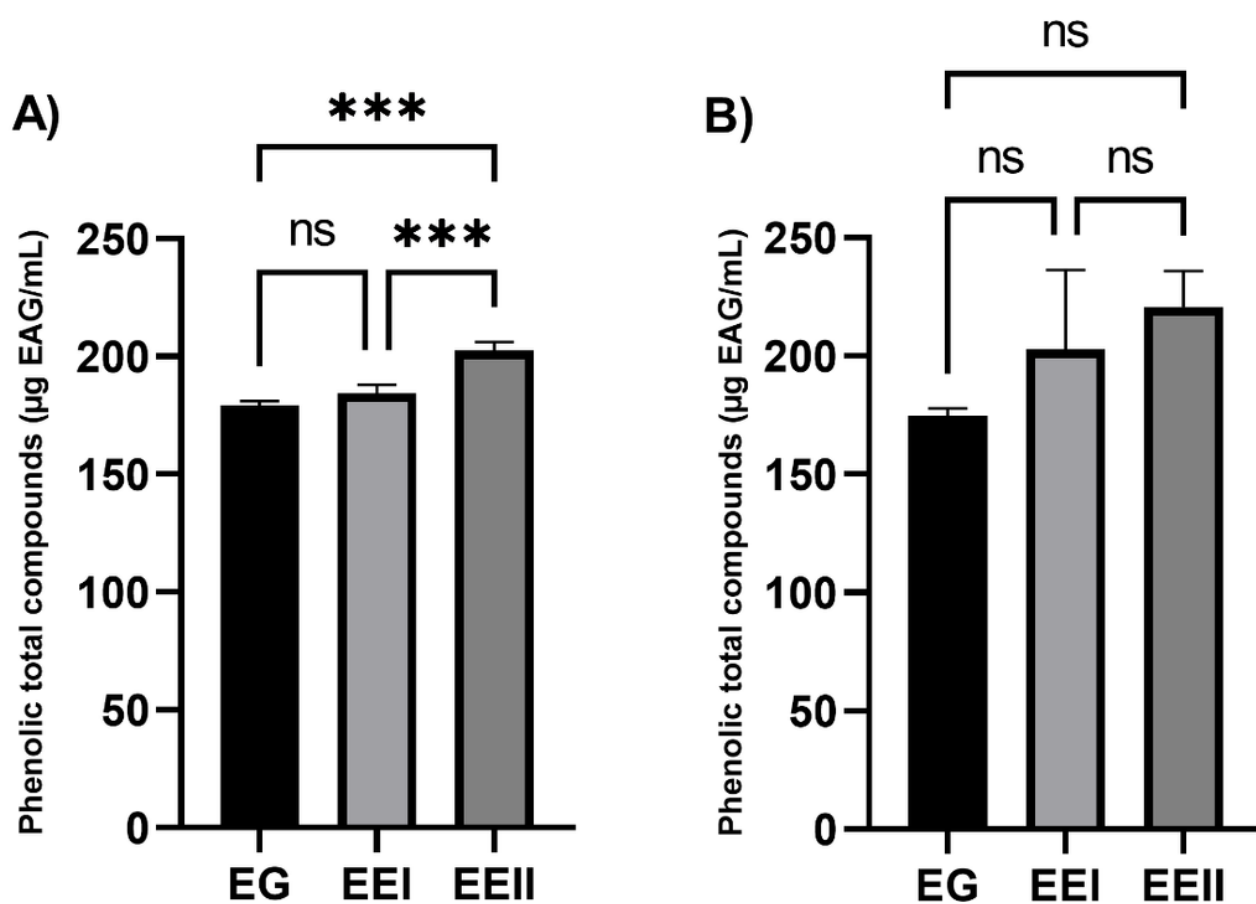


Figure 1

Total phenolic compound content (TPC) of pulp (A) and peel (B) of soursop submitted to the gastric, enteric phase I, and enteric phase II of *in vitro* simulated digestion. EG: Gastric phase, EEI: Enteric phase I, EEII: Enteric phase II. NS = not significant ($p < 0,05$); *** = significant differences ($p < 0,05$). Compared to the Tukey test at 5% probability.

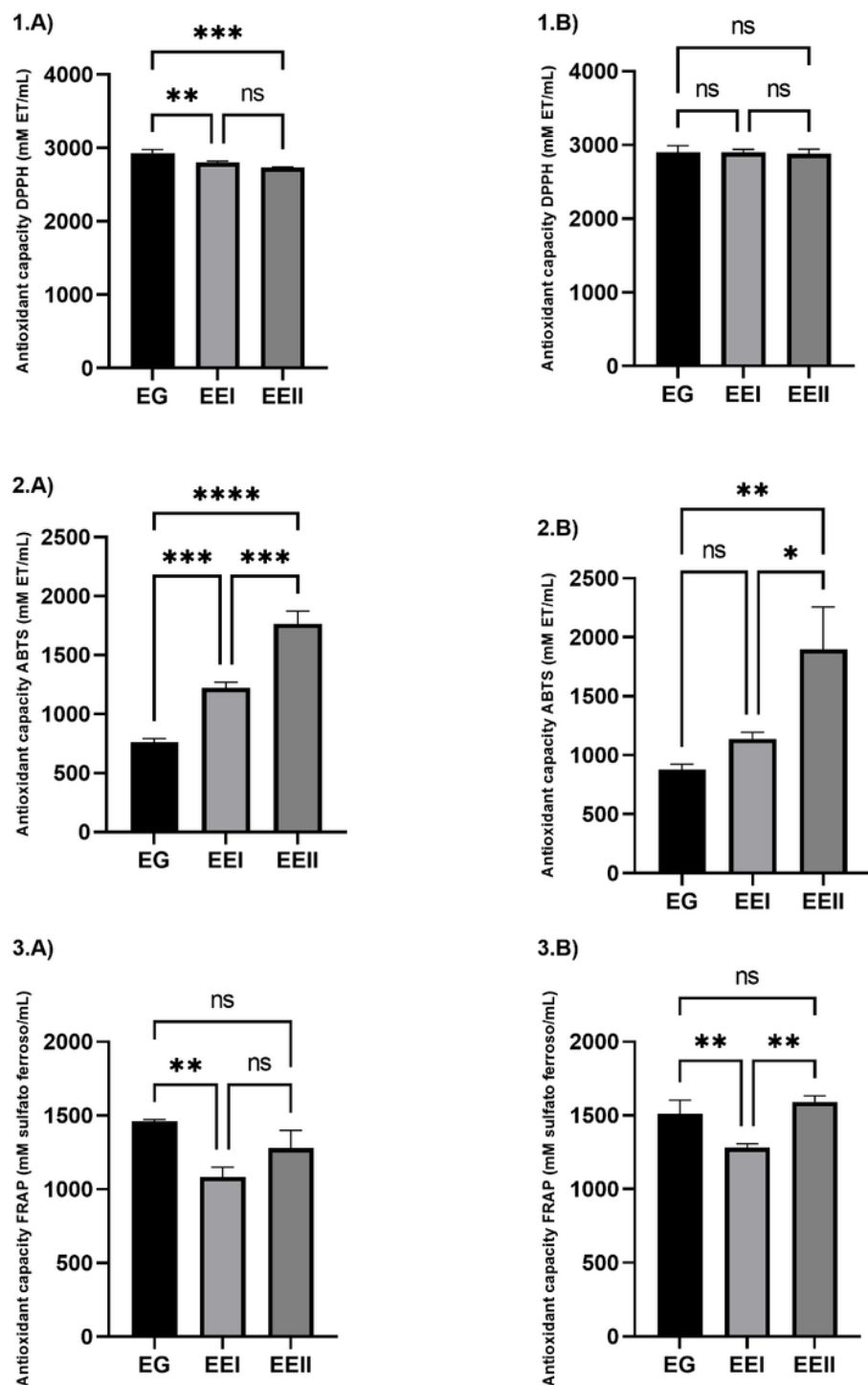


Figure 2

Content antioxidant capacity (DPPH, ABTS e FRAP) of pulp (A) and peel (B) of soursop submitted to the gastric, enteric phase I, and enteric phase II of *in vitro* simulated digestion. EG: Gastric phase, EEI: Enteric phase I, EEII: Enteric phase II. NS = not significant ($p < 0,05$); *** = significant differences ($p < 0,05$). Compared to the Tukey test at 5% probability.

Supplementary Files

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- [SupplementaryMaterialandMethods.docx](#)