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ORIGINAL ARTICLE

Aqueous extraction and drying of yausabara mucilage (*Pavonia sepium* A. St.-Hil.)

Extracción acuosa y secado del mucílago de yausabara (*Pavonia sepium* A. St.-Hil.)

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Abstract The objective of this research work was to evaluate the aqueous extraction process for obtaining mucilage from yausabara (*Pavonia sepium* A. St.-Hil.), a mucilaginous plant found in various wet areas. The research arose from the need to offer alternatives to the agro-industrial sector. The aqueous extracts of the mucilage were obtained from peeled stems, both chopped and ground, using solid-liquid ratios of 1:4 and 1:6, over periods of 6, 12, and 24 hours. The viscosity, turbidity, and total solid content of these extracts were determined. An optimal extraction run was achieved (peeled and chopped stems with a solid-liquid ratio of 1:4 for 20.42 hours), resulting in a viscosity of 51.72 mPa·s, turbidity of 2600 NTU, and a total solid content of 0.87%. The mucilage was precipitated with ethanol from the aqueous extract, and the precipitate was then dried at 40 ºC in an oven for 3 days. The antioxidant capacity and total phenolic content of the obtained powder were determined using the Folin-Ciocalteu and FRAP methods, respectively. The powdered mucilage showed a total phenolic content of 0.0046 mg/g and an antioxidant capacity expressed as Fe^{2+}, of 18.63 µM/g of powder, values that are low compared to those reported for plant-derived extracts.

Keywords yausabara, mucilage, ethanol, distilled water, extraction.

Resumen El objetivo del presente trabajo de investigación fue evaluar el proceso de extracción acuosa para la obtención del mucílago de yausaba (*Pavonia sepium* A. St.-Hil.), una planta mucilaginosa que se encuentra en distintos terrenos húmedos. La investigación surgió de la necesidad de ofrecer alternativas al sector agroindustrial. La obtención de los extractos acuosos del mucílago se realizó a partir de tallos pelados, tanto troceados como molidos, utilizando relaciones sólido-líquido de 1:4 y 1:6, durante períodos de 6, 12 y 24 horas. Se determinó la viscosidad, turbidez y contenido de sólidos totales de dichos extractos. Se obtuvo una corrida con óptimas condiciones de extracción (tallos pelados y troceados con una relación sólido-líquido de 1:4 durante 20,42 horas), que arrojó como resultado una viscosidad de 51,72, una turbidez de 2600 NTU y un contenido de sólidos totales de 0,87%. El mucílago se precipitó con etanol a partir del extracto acuoso, y luego se realizó el secado del precipitado a 40 ºC en estufa durante 3 días. Al polvo obtenido se le determinó su capacidad antioxidante y contenido de polifenoles totales mediante los métodos Folin-Ciocalteu y FRAP, respectivamente. El mucílago en polvo presentó un contenido de polifenoles totales de 0,0046 mg/g y una capacidad antioxidante expresada como Fe^{2+}, de 18,63 µM/g de polvo, valores bajos en comparación con los reportados para extractos de origen vegetal.

Palabras clave yausabara, mucílago, etanol, agua destilada, extracción.

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PUBLIS EDITORIAL

Introduction

Yausabara (*Pavonia sepium* A. St.-Hil.) is a plant native to tropical regions that has garnered increasing interest in research due to its functional properties and potential applications in the food and pharmaceutical industries. This species is characterized by its high mucilage content, a gelatinous substance found in its aerial parts and roots. The mucilage from yausabara exhibits emulsifying, gelling, and stabilizing properties, making it a valuable component for the formulation of food products and medicinal applications (Quezada et al., 2016).

In the context of its extraction, an aqueous extraction process was conducted to maximize the recovery of mucilage. This method is known for being efficient and sustainable, as it uses water as a solvent, minimizing environmental impact and being safe for human consumption. It was considered that aqueous extraction would yield high-quality mucilage, preserving the functional properties characteristic of this plant (Chandran et al., 2023).

The extraction process was carried out at different temperatures and contact times, allowing for the evaluation of the influence of these factors on the yield of the extracted mucilage. Extraction conditions are crucial, as they can affect both the quantity and quality of the mucilage obtained. This study aimed to determine the optimal conditions for aqueous extraction, as well as the subsequent oven drying, which is a fundamental step for the preservation and storage of mucilage (Bazezew et al., 2022).

Drying the mucilage was considered a critical aspect, as it influences the stability and functional properties of the final product. Different drying temperatures and times were evaluated, seeking to maintain the integrity of the mucilage and its functional characteristics (Santos et al., 2023). Appropriate drying techniques can contribute to obtaining mucilage with a longer shelf life and ease of use in food and pharmaceutical formulations. The objective of this study was to evaluate the aqueous extraction process for obtaining yausabara mucilage and its subsequent oven drying.

Materials and methods

The software Design Expert 8.0.6 (Stad-Ease Inc., Minneapolis, USA) was used for experimental design and result analysis, aiming to obtain a raw aqueous extract of yausabara mucilage that exhibited adequate viscosity and a higher total solids content. A numerical optimization method was applied using a fourth-order optimal response surface design, which generated a mathematical model to describe the variations of the variables in each experimental run.

The evaluated factors included extraction time (A), the degree of crushing of yausabara stems (B), and the solid-to-liquid ratio (C). The response variables were viscosity and total solids content. The software defined ten experimental combinations, of which two were replicates. Table 1 shows the matrix of the experimental design. The study evaluated three factors: extraction time (A), a numerical and discrete variable measured in hours (h) with a range of 6 to 24 hours; the degree of grinding (B), a categorical nominal variable with two levels (1 and 2); and the solid/liquid ratio (C), also categorical and nominal, with the same two levels (1 and 2). These factors were analyzed to assess their impact on the outcome of the process.

For the numerical optimization of the design, constraints were established on the dependent variables, based on the recommended criteria for the applications of the raw aqueous extract of the mucilage. Finally, one of the proposed solutions was selected, which was considered the optimized raw extract.

Table 1. Experimental design matrix for aqueous extraction

Run	Extraction time (h)	Grinding degree[a]	Solid/liquid ratio[b]
1	12	1	1
2	24	1	1
3	24	2	2
4	12	2	2
5	12	2	2
6	24	2	1
7	12	1	1
8	6	1	2
9	6	2	1
10	24	1	2

a: 1, chopped (peeled stem of 2 cm and macerated); 2, ground (peeled stem and crushed, cut to 10 cm).

b: 1, solid/water ratio of 1/4; 2, solid/water ratio of 1/6

To validate the optimization, the determination of total sugar content, osmolality, and sensory acceptance of the optimized beverage was carried out in three repetitions. The obtained results were compared with the values predicted by the numerical optimization of the design.

Results and discussion

Table 2 shows the values of viscosity, total solids, and turbidity of the raw aqueous extracts of yausabara. It can be observed that as the extraction time decreased; the viscosity of the raw extract was low, which could be attributed to the degree of grinding and the solid-liquid ratio (Quitério et al., 2022). The ten runs showed that a shorter extraction time resulted in a lower amount of total solids, again influenced by the degree of grinding and the solid-liquid ratio.

Regarding the turbidity of these runs, similar ranges were noted in runs 1, 2, and 10, despite having different extraction times. In runs 1 and 2, the degree of grinding was the same, and in all three runs, the solid-liquid ratio was identical. Runs 3 and 7 exhibited high turbidity values, ranging from 2070 NTU to 2020 NTU, while run 8 showed the lowest turbidity at 910 NTU, which was due to the degree of grinding, as this was performed by chopping.

Table 3 presents the significance of the analysis of variance for the regression and the estimated coefficients for the response variable, which is the viscosity of the raw yausabara extract and the total solids content of the crude aqueous extract of yausabara. It can be seen that the quadratic response surface model was significant at a 95.0% confidence level. The R^2 statistic indicated that the adjusted model explained 99.49% of the variability in viscosity. It is observed

Table 2. Indicators of the raw aqueous extracts of yausabara based on the experimental design.

Run	Viscosity (mPa.s)	Total solids (%)	Turbidity (NTU)
1	80.8	0.75	1400
2	41.58	0.61	1350
3	30.36	0.89	2070
4	13.5	0.55	1060
5	20.1	0.49	1080
6	28.26	0.74	1650
7	76.7	0.84	2020
8	14.28	0.41	910
9	11.7	0.46	1120
10	14.94	0.47	1470

Table 3. Analysis of variance of the quadratic response surface model for the viscosity of the raw mucilage extract of yausabara and 2FI response surface model for the total solids content of the crude mucilage extract of yausabara.

Source	Quadratic response surface	2FI response surface model
	p-value	*p*-value
Model	0.0176	0.0151
A	0.1570	0.0219
B	0.0130	0.7148
C	0.0084	0.0153
AB	0.0186	0.0059
AC	0.0420	0.0262
BC	0.0659	0.0123
A^2	0.0539	-
R^2	0.9949	0.9767
Lack of fit	-	0.7582

A: extraction time; B: degree of grinding; C: solid/liquid ratio.

that the two-factor interaction (2FI) response surface model was significant at a 95.0% confidence level. Additionally, the R^2 statistic indicates that the fitted model explained 97.67% of the variability in turbidity.

It can be observed that both the degree of grinding (B) and the solid-liquid ratio (C) had an effect ($p \leq 0.05$) on the viscosity of the raw yausabara mucilage extract. The equation of the model is:

$$V = 44.218125 + 4.305\,A - 10.974375\,B - 13.659375\,C + 11.499375\,AB + 7.524375\,AC + 7.185\,BC - 19.738125\,A^2 \quad \textbf{(Eq. 1)}$$

Where the viscosity (V) of the extract was measured in mPa·s and was determined based on several factors. These factors included the extraction time (A), expressed in hours, the degree of grinding (B) of the yausabara stems, and the solid-liquid ratio (C) used during the extraction process.

It can be observed that both extraction time (A) and solid/liquid ratio (C) had a significant impact ($p \leq 0.05$) on the total solids content of the crude mucilage extract of yausabara. The equation of the obtained model is:

$$ST = 0.59976744 + 0.07918605\,A + 0.0059375\,B - 0.0740625\,C + 0.1315625\,AB + 0.0765625\,AC + 0.07976744\,BC \quad \textbf{(Eq. 2)}$$

According to the equation, ST refers to the total solids expressed as a percentage, while variables A, B, and C represent extraction time in hours, degree of grinding, and solid/liquid ratio, respectively.

The analysis of the equation's coefficients reveals that the degree of grinding (B) exerted the most significant influence on the dependent variable, followed closely by the interaction term between extraction time and degree of grinding (AB). To verify the normality assumption, we analyzed the normal probability of the residuals using an analysis of variance. The results showed that the internally studentized residuals aligned closely with a straight line, indicating that the errors conform to a normal distribution, thereby supporting the normality hypothesis (Feng et al., 2020).

It can be observed that the values of the internally studentized residuals aligned in a straight line, indicating a normal distribution of the errors and thus confirming the normality hypothesis. For the numerical optimization of the aqueous extraction process of yausabara mucilage, the evaluated intervals of the independent variables, which include extraction time, degree of grinding, and solid/liquid ratio, were used as constraints, to achieve a viscosity a viscosity of 60 mPas and a higher total solid content in the crude extract (Table 4).

Table 5 presents the six optimized solutions for the aqueous extraction process of yausabara mucilage, based on the

Table 4. Constraints for the optimization of the clarification process

Parameter	Lower limit	Upper limit	Criteria
Extraction time (h)	6	24	In the Interval
Degree of grinding	1	2	In the Interval
Solid/liquid ratio	1	2	In the Interval
Viscosity (cP)	11.7	80.8	60
Total solids (%)	0.41	0.89	Maximize

a: 1, chopped (peeled stem of 2 cm and macerated); 2, ground (peeled stem and crushed, cut to 10 cm).

b: 1, solid/water ratio of 1/4; 2, solid/water ratio of 1/6.

Table 5. Results of the numerical optimization of the aqueous extraction process of yausabara mucilage

Solution	Extraction time (h)	Grinding degree[a]	Solid/liquid ratio[b]	Viscosity (mPas)	Total solids (%)	Statistical convenience
1	20.42	1	1	60.0001	0.669962	0.73592617
2	6.00	1	1	71.0175	0.876599	0.67615198
3	23.16	2	2	31.7	0.871793	0.63116768
4	19.97	2	1	38.2786	0.674029	0.55017094
5	18.04	1	2	32.2112	0.448163	0.18374751
6	17.93	1	2	32.3695	0.447862	0.18372797

a: 1, chopped (peeled stem of 2 cm and macerated); 2, ground (peeled stem and crushed, cut to 10 cm).
b: 1, solid/water ratio of 1/4; 2, solid/water ratio of 1/6.

previously established constraints. Solution 1 was chosen as it met the viscosity restriction and demonstrated the greatest statistical convenience.

The results of the determinations made on the crude extract under optimal conditions. The indicators obtained in the study include an average viscosity of 51.72 mPas, a total solids content of 0.87%, and a turbidity of 2600 NTU. This extract was obtained using a solid/liquid ratio of 1:4, with a chopped degree of crushing and an extraction time of 20.42 hours. As a result, a viscosity was obtained that is at the minimum range compared to the mucilage of the nopal (Vargas-Rodríguez et al., 2016).

The total solids are in the intermediate range between runs 3 and 7. The turbidity of this run exceeds that of the main runs due to the shorter resting time. The powdered mucilage showed a total polyphenol content of 0.0046 mg/g and an antioxidant capacity expressed as Fe^{2+}, determined by the FRAP method, of 18.63 μM/g of powder, low values compared to those reported for plant-derived extracts. These values are possibly related to residual polyphenols left over from the extraction and precipitation of the mucilage from the crude aqueous extract.

Aloe vera (*Aloe vera* Barbadensis) is a xerophytic and succulent species native to Africa; it has been identified with 75 active principles; it contains phenolic compounds, mainly chromones and anthraquinones (Liu et al., 2013), located in the inner layer of epidermal cells. The gelatinous and colorless parenchyma mainly consists of water, mucilages, organic acids and salts, enzymes, saponins, tannins, traces of alkaloids, and vitamins.

The phenolic compounds present in aloe vera act as free radical scavengers or metal chelators, causing an antioxidant effect. Hęś et al. (2019) suggested that a high content of flavonoids and anthraquinones is present in aloe vera. The rings of flavonoids have great potential to inhibit the generation of reactive oxygen species; glycosylated flavonoids are often found in healthy leaves and possess reducing activity.

Of all secondary metabolites, phenolic compounds show a linear correlation between concentration and antioxidant capacity expressed in Trolox and ascorbic acid equivalents, particularly flavonoids. Adrianzén (2018) determined the antioxidant capacity using the ORAC method and total polyphenol content through the Folin-Ciocalteu method for the peel and mucilage of *Coffea arabica* L. The study reported antioxidant capacity values expressed as Trolox of 0.0412 μM/g and total polyphenols expressed as gallic acid of 17.21 mg/g of mucilage extract using methanol as a solvent. Both determinations corresponded to low values for both indicators, similar results to those of the present study. However, it should be noted that the difference in matrices from which the mucilaginous extracts were obtained (yausabara and coffee), in addition to the differences in analytical methods, specifically in determining antioxidant capacity, limits comparisons.

Conclusions

The results identified an optimal run using peeled and chopped stems, achieving an adequate viscosity and significant total solids content. The analyses of polyphenols and antioxidants revealed a low content, suggesting that, despite these results, the drying process did not affect the properties of the mucilage, as it was carried out at appropriate temperatures and times. This indicates the potential of yausabara mucilage as a viable option in agro-industrial applications, despite the reduced levels of bioactive compounds.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

Author contributions

Evelin M. Chillagana, Dayanna E. Veloz and Franklin A. Molina: Conceptualization, data curation, formal analysis, investigation, methodology, supervision, validation, visualization, drafting the original manuscript and writing, review, and editing.

Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Statement on the use of AI

The authors acknowledge the use of generative AI and AI-assisted technologies to improve the readability and clarity of the article.

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