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Optimization of ultrasound-assisted extraction of crude polysaccharides and polyphenols from passion fruit peels

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ABSTRACT

Introduction: This study aimed to optimize the conditions of ultrasound-assisted extraction to simultaneously obtain the highest yields of polysaccharides and polyphenols from passion fruit (*Passiflora edulis*) peels. **Methods:** Box–Behnken design (BBD) and response surface methodology were employed for the optimization. The factors and their levels studied in BBD included a solvent-to-solid ratio (X_1) of 30-70 mL/g, an ultrasonic temperature (X_2) of 40-70°C and an ultrasonic duration (X_3) of 40-70 min. The results revealed that the optimal conditions were an X_1 of 53.9 mL/g, an X_2 of 57.6°C, and an X_3 of 57.0 min. Under these optimized conditions, the predicted yields of polysaccharides and polyphenols were 36.46% and 48.35 mg gallic acid equivalent (GAE)/g, respectively. The experimental data, which were 35.76 ± 1.54% and 47.51 ± 1.77 mg GAE/g, respectively, agreed well with the predicted data and hence validated the good fit of the models. **Conclusion:** This study demonstrated that the ultrasound-assisted extraction method could be effective and ecologically benign for extracting bioactive compounds and natural ingredients from agricultural sources.

Key words: ultrasound, passion fruit, polysaccharides, polyphenols, extraction, optimization

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INTRODUCTION

Passion fruit (*Passiflora edulis*) originates from the American tropics and is introduced to and grown in most subtropical and tropical parts of the world. According to Morton (1987) [1], passion fruit has naturalized and spread throughout the tropics and subtropics, including Southeast Asia. Considering the current research trends on passion fruit, its peels are receiving the attention of researchers because they constitute approximately 50−60% of the fruit weight [2] and are the main waste from juice processing. Passion fruit peels contain a significant amount of bioactive compounds such as polyphenols and functional compounds such as polysaccharides [3]. Both bioactive polyphenols and polysaccharides have been reported to have biological effects on the body, to protect against degenerative and chronic diseases, and to inhibit mutagenesis and carcinogenesis. These substances have also been linked to antiviral, antiallergic, antiplatelet, and anti-inflammatory properties [4].

Extraction is the most essential step for the isolation and identification of polysaccharides and polyphenols. Alternative extraction techniques have evolved over the last few decades as a result of their time-saving and environmentally benign characteristics, as well as their cost-effective output of high-quality extracts [5]. Ultrasound-assisted extraction (UAE) is a novel approach that has been successfully used to extract a variety of substances with various advantages. Its application minimizes extraction time, reduces solvent usage, and provides great repeatability. Previous investigations have demonstrated that this process is a green and cost-effective alternative to traditional procedures for food and natural products, such as maceration, Soxhlet extraction, and Clevenger distillation [6–9]. Due to cell disruption caused by cavitation, the use of ultrasonic energy can also aid in the extraction of plant components [10]. Although UAE has been used to extract certain bioactive compounds or polysaccharides from passion fruit peels, these substances can be extracted individually [11,12]. Therefore, this study aimed to employ UAE for the simultaneous extraction of both components. In addition, optimization using response surface methodology (RSM) in conjunction with Box–Behnken design (BBD) was also applied to determine the optimal process conditions and formulate models describing the process.

MATERIALS AND METHODS

Materials and chemicals

Fresh passion fruit peels were collected at a juice shop in Thu Duc city, transferred to the laboratory, washed and dried on the same day at 60°C overnight so that the sample moisture was less than 10%. Afterward,

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the dried samples were ground and sieved through 500 μm mesh to obtain a uniform powder. The passion fruit peel powder (PFPP) was collected, sealed in small bags (50 g each), and stored in a refrigerator for further use. Chemicals of analytical grade were used for extraction and analyses.

Ultrasound-assisted extraction

The ultrasound-assisted extraction was carried out by adapting the approach of Ahmad et al. (2015)[13]. In detail, various amounts of PFPP were mixed with 20 mL of sodium acetate buffer (pH 5) to achieve different solvent-to-solid ratios ranging from 30-70 mL/g. The mixtures were then treated in an ultrasonic bath (WUC-A10H, South Korea) at a frequency of 40 kHz in the temperature range of 40-70°C for 40-70 min. After treatment, the mixtures were quickly cooled to ambient temperature and centrifuged (Z326K, Germany) for 15 minutes at 4°C and 4000 rpm. The supernatants were collected, mixed with 96% ethanol at a ratio of 1:10 (v/v) and kept overnight in a refrigerator for complete precipitation. The precipitated crude polysaccharides were obtained by filtration, and the filtrates were collected for polyphenol recovery.

Box–Behnken design and regression analysis

A Box–Behnken factorial design (BBD) was employed for the optimization of UAE with three variables: the solvent-to-solid ratio, ultrasonication temperature and duration. Table 1 presents the symbols, units, and coded and true levels of these three variables. The design included 12 factorial points (1, +1) and 5 central points (0), while the entire set of tests comprised 17 runs, which were conducted in a random order with three replicates.

The obtained data were fitted to a second-order polynomial equation (quadratic model) as described in Eq. (1) to correlate the relationships between the independent variables and the response:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1}^{k} \beta_{ij} x_i x_j \quad (1)$$

where Y is the response for either PS or TPC; β symbolizes the coefficients; and x represents the coded independent variables.

To assess the statistical significance of the developed model, the F value, p value, coefficient of determination (R^2), adjusted R^2 (R^2_{adj}), and predicted R^2 (R^2_{pred}) were used. The information was then used to create a 3-D response surface. The desirability function methodology was utilized to estimate the optimal extraction conditions.

Analytical methods

PS yield determination

After filtration, the collected crude polysaccharides were dried (UNE 700, Germany) at 130°C until a constant weight was reached to determine the dry solid content. The PS yield was then calculated based on the weight of the obtained polysaccharides divided by the initial weight of PFPP relative to dry matter.

TPC determination

The remaining solution after filtration was used to determine the total phenolic content (TPC) following the method of Kupina et al. (2018)[14] with some modifications. Specifically, 0.5 mL of the polyphenol solution was mixed with 0.5 mL of 10% (v/v) Folin-Ciocalteu solution and 3 mL of distilled water, along with 0.5 mL of sodium carbonate. After thoroughly shaking the tubes for a homogeneous mixture, each tube was wrapped in aluminum foil and placed at room temperature for 45 minutes before being analyzed with a spectrometer (V730, Japan) at 765 nm. The results are expressed as mg gallic acid equivalent per gram dry matter of PFPP (mg GAE/g).

Statistical analysis

Each experiment was performed in triplicate, and the experimental data are expressed as the mean ± standard deviation. Design-Expert software (Trial version, Stat-Ease Inc., USA) was used for ANOVA and optimization.

RESULTS AND DISCUSSIONS

Box–Behnken design and regression analysis

Table 2 presents the experimental data for the BBD matrix with PS yield and TPC as the response. After 17 runs, the PS yield ranged from 8.68 to 36.13%, while the TPC varied between 11.55 and 47.51 mg GAE/g. To investigate the combined effects of independent variables (i.e., the solvent-to-solid ratio, ultrasonic temperature and duration) on the PS yield and TPC from PFPP, quadratic models were constructed with the linear and quadratic terms of each variable and their interactions. Table 3 provides the ANOVA results used to evaluate the models. Both models for PS yield and TPC were highly significant, with p values of < 0.0001 and a nonsignificant lack of fit (p values > 0.05), showing the adequacy of pure error. The coefficients of determination (R^2) were determined to be > 0.998, indicating that the formulated models could explain more than 99.8% of the variability. Furthermore, the predicted R^2 values > 0.97

Table 1: Levels of factors tested in Box–Behnken design (BBD)

Factors	Symbol	Units	Coded level		
			-1	0	1
Solvent-to-solid ratio	X_1	mL/g	30	50	70
Ultrasonic temperature	X_2	^oC	40	55	70
Ultrasonic duration	X_3	minute	40	55	70

Table 2: Box–Behnken design of factors (in coded levels) with the polysaccharide yield (PS) and total phenolic content (TPC) as the response

No.	X_1	X_2	X_3	PS yield (%)		TPC (mg GAE/g)	
				Experimental value	Predicted value	Experimental value	Predicted value
1	-1	-1	0	8.68 ± 1.24	8.48	11.55 ± 2.18	10.94
2	1	-1	0	27.60 ± 2.44	26.77	39.57 ± 1.24	39.33
3	-1	1	0	16.85 ± 1.08	17.26	19.62 ± 3.01	19.69
4	1	1	0	23.17 ± 1.26	23.42	36.57 ± 2.43	37.19
5	-1	0	-1	12.85 ± 2.17	12.82	12.52 ± 1.11	13.22
6	1	0	-1	24.62 ± 1.26	24.75	35.61 ± 2.05	35.78
7	-1	0	1	17.96 ± 0.99	17.69	19.46 ± 2.15	19.28
8	1	0	1	25.19 ± 1.95	25.09	37.49 ± 2.51	36.76
9	0	-1	-1	20.71 ± 1.91	21.06	30.19 ± 1.65	30.13
10	0	1	-1	25.85 ± 2.13	25.41	38.23 ± 2.19	37.45
11	0	-1	1	22.17 ± 0.99	22.75	33.91 ± 0.98	34.73
12	0	1	1	29.16 ± 1.82	28.95	39.77 ± 1.43	39.87
13	0	0	0	35.28 ± 2.44	35.67	46.18 ± 1.93	46.66
14	0	0	0	35.42 ± 0.54	35.67	46.56 ± 1.67	46.66
15	0	0	0	36.13 ± 3.14	35.67	46.69 ± 3.13	46.66
16	0	0	0	35.76 ± 1.54	35.67	47.51 ± 1.77	46.66
17	0	0	0	35.49 ± 1.85	35.67	46.27 ± 2.33	46.66

were reasonably consistent with the adjusted R^2 value of 0.99. Desirable Adeq. Precision values greater than 4 also indicated appropriate signals for the models. Second-order polynomial models representing the correlation between the three independent variables (in their coded levels) and responses were produced in Equations (2) and (3) as follows:

$$Y_1(\%) = 35.8 + 1.93X_1 - 1.14X_2 - 0.9702X_3 - 0.5849X_1X_2 - 0.3785X_1X_3 + 0.2053X_2X_3 - 2.8X_1^2 - 3X_2^2 - 1.94X_3^2 \quad (2)$$

$$Y_2(mg\ GAE/g) = 46.98 + 4.58X_1 - 0.7229X_2 - 1.21X_3 - 0.4218X_1X_2 - 0.4227X_1X_3 - 0.2427X_2X_3 - 3.83X_1^2 - 2.68X_2^2 - 2.26X_3^2 \quad (3)$$

where Y_1 and Y_2 are the responses (PS yield and TPC, respectively), and X_1, X_2 and X_3 are the independent variables, i.e., the solvent-to-solid ratio, ultrasonic temperature and duration, respectively.

The predicted data of the responses obtained from the two models are presented in Table 2 for comparison

Table 3: ANOVA for Box–Behnken Design for PS and TPC as the response

		PS			TPC		
Source	DF	Coefficient Estimate	F Value	P Value	Coefficient Estimate	F Value	P Value
Model	9	35.8000	430.0400	< 0.0001	46.9800	414.5200	< 0.0001
X_1	1	1.9300	276.5300	< 0.0001	4.5800	746.4100	< 0.0001
X_2	1	-1.1400	38.3100	0.0004	-0.7229	7.3700	0.0300
X_3	1	-0.9702	27.3600	0.0012	-1.2100	20.5100	0.0027
X_1X_2	1	-0.5849	30.1300	0.0009	-0.4218	7.5300	0.0288
X_1X_3	1	-0.3785	17.4800	0.0041	-0.4227	10.4700	0.0143
X_2X_3	1	0.2053	2.8900	0.1327	-0.2427	1.9400	0.2060
X_1^2	1	-2.8000	1490.9000	< 0.0001	-3.8300	1335.0400	< 0.0001
X_2^2	1	-3.0000	642.4100	< 0.0001	-2.6800	245.3000	< 0.0001
X_3^2	1	-1.9400	262.6900	< 0.0001	-2.2600	171.1800	< 0.0001
Lack of Fit	3		4.6900	0.0848		3.7800	0.1159
R^2		0.9982			0.9981		
Adjusted R^2		0.9959			0.9957		
Predicted R^2		0.9767			0.9749		
Adeq. Precision		65.2546			59.4188		
C.V. %		2.1300			2.2700		

Table 4: Predicted and experimental responses under optimal conditions

	Predicted	Experimental
Solvent-to-solid ratio (mL/g)	53.9	54
Ultrasonic temperature (^oC)	57.6	58
Ultrasonic duration (min)	57.0	57
PS yield (%)	36.46	35.76 ± 1.54
TPC (mg GAE/g)	48.35	47.51 ± 1.77

with their experimental values. The results in Table 3 indicate that all three variables had significant effects on both responses at their linear and quadratic levels (X and X^2), with p values < 0.05. On the other hand, the interaction effects of X_1X_2 and X_1X_3 were significant (p < 0.05), and those of X_2X_3 were negligible (p > 0.05) for both responses.

3D-surface responses

To further understand the interaction of variables, 3D response surface graphs (Figure 1) were generated by plotting the response against two independent variables while holding the third constant at its zero level. The images illustrated that both the PS yield and TPC were low at the lowest solvent-to-solid ratio (30 mL/g). These responses markedly increased with increasing solvent-to-solid ratio but slightly decreased at the highest concentration of 70 mL/g. These observations align well with the principles of mass transfer, which suggest that the concentration gradient between the solid and the solvent drives the transfer of mass [15]. A higher solvent-to-solid ratio amplifies this gradient, accelerating the diffusion rate of chemicals from the solid material into the solvent. However, it also prolongs the time needed to achieve equilibrium. The solvent-to-solid ratio can profoundly influence

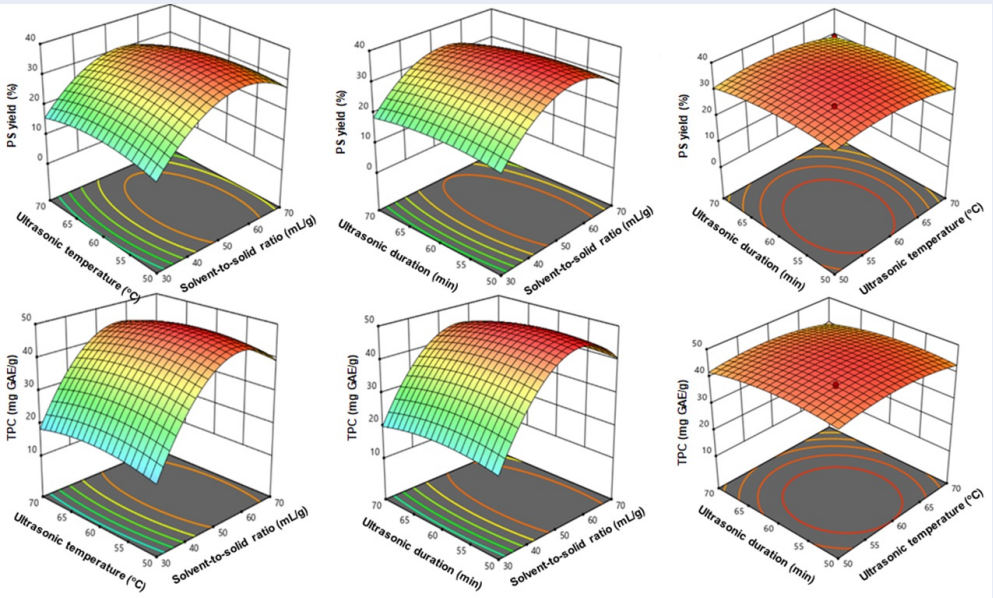

Figure 1: The effects of two process variables, namely ultrasonic temperature and solvent-to-solid ratio, ultrasonic duration and solvent-to-solid ratio, and ultrasonic duration and ultrasonic temperature on PS yield (upper row) and TPC (lower row)

the equilibrium constant, revealing a relationship between yield and solvent consumption characterized by an exponential increase followed by a plateau as the maximum yield approaches [16].

Similar trends were also observed for the effects of ultrasonic temperature and duration. A lower ultrasonic temperature could reduce the solubility of the target compounds in the solvent, leading to insufficient extraction efficiency [17]. Furthermore, some plant materials may require higher temperatures to effectively breakdown cell walls for the release of their internal substances. However, at elevated temperatures (higher than 60°C in this study), both responses decreased with increasing temperature. This may be due to membrane denaturation at high temperatures, causing difficulty in substance diffusion into the solvent, or due to the instability of phenolic compounds at high temperatures [18]. On the other hand, increasing the ultrasonication duration to less than 60 min could improve the extraction yield by softening plant tissues, weakening cell wall integrity, and hydrolyzing phenolic-protein, polysaccharide-protein, and phenolic-polysaccharide complex bonds, as well as increasing the solubility of target compounds in the solvent [19]. In contrast, extending sonication beyond 60 minutes resulted in a lower extraction efficiency for PS yield and TPC. This could be attributed to structural alterations in polyphenols [20] or polymeric breakdown of polysaccharides [21].

Optimization and validation

The trade-offs among numerous variables were balanced to simultaneously optimize two responses, i.e., PS yield and TPC. The results in Table 4 present the optimal conditions, including a solvent-to-solid ratio of 53.9 mL/g, an ultrasonication temperature of 57.6°C and an ultrasonication duration of 57 min. Meanwhile, the predicted optimal response values were 36.46% and 48.35 mg GAE/g for the PS yield and TPC, respectively. The data obtained from the experiment under the optimal conditions with minor modifications to the variable levels, as shown in Table 4, aligned well with their predicted values, which were 35.76 ± 1.54% and 47.51 ± 1.77 mg GAE/g for PS yield and TPC, respectively. This could confirm the adequacy and significance of the models. Compared with the efficiency of individual extraction, the yield of polysaccharides in this study was greater than that previously reported by Pereira et al. (2024) [22] using pressurized solvent extraction, by Vasco-Correa and Zapata (2017) [23] using enzymatic extraction, or by Kulkarni and Vijayanand (2010) [2] using the conventional method (28%, 26% and 15%, respectively). Moreover, the TPC in this study seemed to be slightly greater than that recorded by Wang et al. (2021) [24] using the cellulase-assisted extraction method or by Vo et al. (2023) [25] using UAE under milder conditions (liquid-to-solid ratio of 28 mL/g and 20 min) for single extraction (22.34 mg GAE/g and 39.38 mg GAE/g,

respectively). The difference may be due to variations in the employed methods, extraction conditions and materials. For example, in this study, pH 5 buffer was used as the solvent for the extraction. Although water extraction has been applied as the traditional method for the extraction of natural polysaccharides, acidic environments have been demonstrated to enable more effective cleavage of glycoside bonds, resulting in higher yields of bioactive low-molecular-weight polysaccharides[26–28]. In addition, although various solvents, such as ethanol, methanol, or natural deep eutectic solvents, are commonly used to extract phenolics, acidic conditions have been revealed for their ability to hydrolyze glycoside bonds in phenolic derivatives and transform them into free phenolics for easier release[29–31]. Therefore, the use of acidic buffer may be effective for the coextraction of both polysaccharides and polyphenols. In conclusion, these comparisons implied the potential benefits of simultaneous extraction of polysaccharides and polyphenols using pH 5 buffer with the UAE method.

CONCLUSION

This study aimed to conduct two-response optimization for the ultrasound-assisted extraction of polysaccharides and polyphenols from PFPP using response surface methodology. By using a three-variable, three-level Box–Behnken design (BBD), the optimal extraction conditions to obtain the highest PS yield (36.46%) and TPC (48.35 mg GAE/g) were as follows: 53.89 mL/g, 57.62°C, and 56.99 min for the solvent-to-solid ratio, ultrasonication temperature and duration, respectively. Furthermore, it was discovered that the experimental response values were closely comparable to the predicted values, indicating that the models were good fits and capable of making accurate predictions. Future research should focus on comprehensive characterizations of the obtained polysaccharides and polyphenols for their potential applications.

ABBREVIATIONS

BBD : Box–Behnken design
GAE : gallic acid equivalent
PBD : Plackett–Burman design
PFPP : passion fruit peel powder
PS : polysaccharide
RSM : response surface methodology
TPC : total phenolic content
UAE : ultrasound–assisted extraction

AUTHOR CONTRIBUTIONS

Minh K. Q. Le: Conceptualization, Methodology, Formal analysis, Investigation, Writing - Original Draft; Ngoc Lieu Le: Conceptualization, Validation, Resources, Writing - Review & Editing, Supervision, Project administration, Funding acquisition.

COMPETING INTERESTS

The authors declare that they have no competing interests.

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REFERENCES

1. Morton JF. Fruits of warm climates. Oregon, USA: Wipf and Stock Publishers; 1987. 505 p;.
2. Kulkarni SG, Vijayanand P. Effect of extraction conditions on the quality characteristics of pectin from passion fruit peel (Passiflora edulis f. flavicarpa L.). LWT - Food Science and Technology. 2010;43(7):1026-31;Available from: https://doi.org/10.1016/j.lwt.2009.11.006.
3. López-Vargas JHF-L, J , Pérez-Álvarez JA, Viuda-Martos M. Chemical, physico-chemical, technological, antibacterial and antioxidant properties of dietary fiber powder obtained from yellow passion fruit (Passiflora edulis var. flavicarpa) coproducts. Food Research International. 2013;51(2):756-63;Available from: https://doi.org/10.1016/j.foodres.2013.01.055.
4. Xie J-H, Jin M-L, Morris GA, Zha X-Q, Chen H-Q, Yi Y. Advances on bioactive polysaccharides from medicinal plants. Critical Reviews in Food Science and Nutrition. 2016;56(1):S60-S84;Available from: https://doi.org/10.1080/10408398.2015.1069255.
5. Wang L, Weller CL. Recent advances in extraction of nutraceuticals from plants. Trends in Food Science & Technology. 2006;17(6):300-12;Available from: https://doi.org/10.1016/j.tifs.2005.12.004.
6. Chemat F, Rombaut N, Sicaire AG, Meullemiestre A, Fabiano-Tixer AS, Albert-Vian M. Ultrasound assisted extraction of food and natural products. Mechanism, Techniques, combinations, protocols and applications. A review. Ultrasonics Sonochemistry. 2017;34:540-60;Available from: https://doi.org/10.1016/j.ultsonch.2016.06.035.
7. Mousavi SA, Nateghi L, Javanmard Dakheli M, Ramezan Y, Piravi-Vanak Z. Maceration and ultrasound-assisted methods used for extraction of phenolic compounds and antioxidant activity from Ferulago angulata. Journal of Food Processing and Preservation. 2022;46(3):e16356;Available from: https://doi.org/10.1111/jfpp.16356.
8. Heleno SA, Diz P, Prieto M, Barros L, Rodrigues A, Barreiro MF, et al. Optimization of ultrasound-assisted extraction to obtain mycosterols from Agaricus bisporus L. by response surface methodology and comparison with conventional Soxhlet extraction. Food Chemistry. 2016;197:1054-63;Available from: https://doi.org/10.1016/j.foodchem.2015.11.108.
9. Gholivand MB, Yamini Y, Dayeni M. Optimization and comparison of ultrasound-assisted extraction of estragole from Tarragon leaves with hydrodistillation method. Analytical and Bioanalytical Chemistry Research. 2014;1(2):99-107;.
10. Zhu Z, He J, Liu G, Koubaa FJBM, Ding L, Bals O, et al. Recent insights for the green recovery of inulin from plant food materials using nonconventional extraction technologies: A review. Innovative Food Science & Emerging Technologies. 2016;33:1-9;Available from: https://doi.org/10.1016/j.ifset.2015.12.023.

11. Oliveira CF, Giordani D, Lutckemier R, Gurak PD, Cladera-Olivera F, Marczak LDF. Extraction of pectin from passion fruit peel assisted by ultrasound. LWT-Food Science and Technology. 2016;71:110-5;Available from: https://doi.org/10.1016/j.lwt.2016.03.027.
12. Souza CG, Rodrigues TH, e Silva LM, Ribeiro PR, de Brito ES. Sequential extraction of flavonoids and pectin from yellow passion fruit rind using pressurized solvent or ultrasound. Journal of the Science of Food and Agriculture. 2018;98(4):1362-8;Available from: https://doi.org/10.1002/jsfa.8601.
13. Ahmad A, Alkharfy KM, Wani TA, Raish M. Application of Box-Behnken design for ultrasonic-assisted extraction of polysaccharides from Paeonia emodi. International Journal of Biological Macromolecules. 2015;72:990-7;Available from: https://doi.org/10.1016/j.ijbiomac.2014.10.011.
14. Kupina S, Fields C, Roman MC, Brunelle SL. Determination of total phenolic content using the Folin-C assay: Single-laboratory validation, first action 2017.13. Journal of AOAC International. 2018;101(5):1466-72;Available from: https://doi.org/10.5740/jaoacint.18-0031.
15. Tan P, Tan C, Ho C. Antioxidant properties: Effects of solid-to-solvent ratio on antioxidant compounds and capacities of Pegaga (Centella asiatica). International Food Research Journal. 2011;18(2):557;.
16. Hamdan S, Daood HG, Toth-Markus M, Illés V. Extraction of cardamom oil by supercritical carbon dioxide and subcritical propane. The Journal of Supercritical Fluids. 2008;44(1):25-30;Available from: https://doi.org/10.1016/j.supflu.2007.08.009.
17. Jerman T, Trebše P, Vodopivec BM. Ultrasound-assisted solid liquid extraction (USLE) of olive fruit (Olea europaea) phenolic compounds. Food Chemistry. 2010;123(1):175-82;Available from: https://doi.org/10.1016/j.foodchem.2010.04.006.
18. Pinelo M, Rubilar M, Jerez M, Sineiro J, Núñez MJ. Effect of solvent, temperature, and solvent-to-solid ratio on the total phenolic content and antiradical activity of extracts from different components of grape pomace. Journal of Agricultural and Food Chemistry. 2005;53(6):2111-7;Available from: https://doi.org/10.1021/jf0488110.
19. Zhu Z, He J, Liu G, Barba FJ, Koubaa M, Ding L, et al. Recent insights for the green recovery of inulin from plant food materials using nonconventional extraction technologies: A review. Innovative Food Science & Emerging Technologies. 2016;33:1-9;Available from: https://doi.org/10.1016/j.ifset.2015.12.023.
20. Mouhoubi K, Boulekbache-Makhlouf L, Madani K, Freidja ML, Silva AM, Cardoso SM. Microwave-assisted extraction optimization and conventional extraction of phenolic compounds from coriander leaves: UHPLC characterization and antioxidant activity. The North African Journal of Food and Nutrition Research. 2023;7(15):69-83;Available from: https://doi.org/10.51745/najfnr.7.15.69-83.
21. Xu Y, Zhang L, Bailina Y, Ge Z, Ding T, Ye X, et al. Effects of ultrasound and/or heating on the extraction of pectin from grapefruit peel. Journal of Food Engineering. 2014;126:72-81;Available from: https://doi.org/10.1016/j.jfoodeng.2013.11.004.
22. Pereira DTV, Méndez-Albiñana P, Mendiola JA, Villamiel M, Cifuentes A, Martínez J, et al. An eco-friendly extraction method to obtain pectin from passion fruit rinds (Passiflora edulis sp.) using subcritical water and pressurized natural deep eutectic solvents. Carbohydrate Polymers. 2024;326:121578;Available from: https://doi.org/10.1016/j.carbpol.2023.121578.
23. Vasco-Correa J, Zapata ADZ. Enzymatic extraction of pectin from passion fruit peel (Passiflora edulis f. flavicarpa) at laboratory and bench scale. LWT. 2017;80:280-5;Available from: https://doi.org/10.1016/j.lwt.2017.02.024.
24. Wang W, Gao Y-T, Wei J-W, Chen Y-F, Liu Q-L, Liu H-M. Optimization of ultrasonic cellulase-assisted extraction and antioxidant activity of natural polyphenols from passion fruit. Molecules. 2021;26(9):2494;Available from: https://doi.org/10.3390/molecules26092494.
25. Vo TP, Nguyen NTU, Le VH, Phan TH, Nguyen THY, Nguyen DQ. Optimizing ultrasonic-assisted and microwave-assisted extraction processes to recover phenolics and flavonoids from passion fruit peels. ACS omega. 2023;8(37):33870-82;Available from: https://doi.org/10.1021/acsomega.3c04550.
26. Gao J, Lin L, Sun B, Zhao M. A comparison study on polysaccharides extracted from Laminaria japonica using different methods: structural characterization and bile acid-binding capacity. Food & Function. 2017;8(9):3043-52;Available from: https://doi.org/10.1039/C7FO00218A.
27. Yao Y, Xiang H, You L, Cui C, Sun-Waterhouse D, Zhao M. Hypolipidemic and antioxidant capacities of polysaccharides obtained from Laminaria japonica by different extraction media in diet-induced mouse model. International Journal of Food Science & Technology. 2017;52(10):2274-81;Available from: https://doi.org/10.1111/ijfs.13508.
28. Lu J, You L, Lin Z, Zhao M, Cui C. The antioxidant capacity of polysaccharide from Laminaria japonica by citric acid extraction. International Journal of Food Science & Technology. 2013;48(7):1352-8;Available from: https://doi.org/10.1111/ijfs.12072.
29. Şahin S, Demir C, Malyer H. Determination of phenolic compounds in Prunella L. by liquid chromatography-diode array detection. Journal of Pharmaceutical and Biomedical Analysis. 2011;55(5):1227-30;Available from: https://doi.org/10.1016/j.jpba.2011.03.016.
30. Chakraborty D, Mandal S, Chakraborty J, Bhattacharyaa P, Bandyopadhyay A, Mitra A, et al. Antimicrobial activity of leaf extract of Basilicum polystachyon (L) Moench. 2007;45:744-8;.
31. Fogarasi M, Socaciu M-I, Sălăgean C-D, Ranga F, Fărcaș AC, Socaci SA, et al. Comparison of different extraction solvents for characterization of antioxidant potential and polyphenolic composition in Boletus edulis and Cantharellus cibarius mushrooms from Romania. Molecules. 2021;26(24):7508;Available from: https://doi.org/10.3390/molecules26247508.