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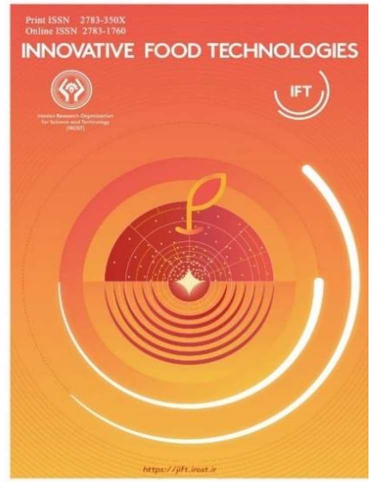

Rheological properties of Wild sage seed gum solution: Effect of different concentrations of ascorbic acid, citric acid, malic acid, and tartaric acid

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Rheological properties of Wild sage seed gum solution: Effect of different concentrations of ascorbic acid, citric acid, malic acid, and tartaric acid

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Abstract

In this study the effect of edible organic acids at two concentrations on the viscosity and rheological behavior of Wild sage seed gum (WSSG) solution was investigated. The apparent viscosity values of the WSSG solution prepared in organic acids model system (0.5 %) were determined to be 10.31, 4.48, 7.00, and 5.49 mPa.s for ascorbic, citric, malic, and tartaric acids, respectively, at the shear rate of 49 s^{-1} and 20°C. The apparent viscosity of the WSSG solution reduced as the organic acids concentration increased from 0.5 to 1 %. The highest decrease in viscosity was related to 1% tartaric and citric acids, and the lowest was related to 0.5% ascorbic acid. Herschel-Bulkley equation was the best model for describing the behavior of WSSG solution containing edible organic acids. This model showed good performance with the maximum correlation coefficient (>0.9956) and minimum error values. The consistency coefficient values of the samples (Power law and HB models) reduced as the acid percent was increased. The sample containing 1% tartaric acid had the lowest consistency coefficient and the sample containing 0.5% ascorbic acid had the highest consistency coefficient. The flow behavior index of the samples increased when the acid concentration was increased.

Keywords: Consistency coefficient; Flow behavior index; Herschel-Bulkley; Wild sage.

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1. Introduction

Gums (hydrocolloids) interact strongly with water and as thickeners play a role in the viscosity, consistency, and textural properties of food products [1]. Different types of gums like Wild sage seed gum (WSSG), Basil seed gum, Balangu seed gum, xanthan, guar, pectin, karaya, carrageenan, locust bean, acacia, carboxymethyl cellulose (CMC), arabic, and alginate are utilized in different kinds of food products like beverages, sauces, dairy products, instant foods, ready-to-use dessert soups, bakery products, and confectionaries [2-6]. The WSSG is a hydrocolloid extracted from the seeds of *Salvia macrosiphon* L. This gum is good for making food thicker and keeping it stable. This makes it a good choice for use in food products. This gum performs very well compared to some commercially available food-grade gums. Aqueous dispersion of this gum produce high viscosity and shear-thinning behavior [7]. The WSSG has a high carbohydrate content (69.01%, d.b.), and a low protein content (2.08%, d.b.). The average moisture, ash, and uronic acids content of this gum are 11.24% (w.b.), 9.20% (d.b.), and 30.2%, respectively. Also, the WSSG is a galactomannan with a 1.78–1.93:1 mannose/galactose ratio and a weight average molecular weight of $\sim 4 \times 10^5$ Da [8].

Organic acids are the organic compounds with the acidic properties, classified based on the number of carboxylic functions. Organic acids are the organic compounds with the acidic properties, classified based on the number of carboxylic functions [9]. Ascorbic acid, a low-cost food additive, has been used for food preservation and against browning [10]. Alpha-hydroxyl acids are a class of organic acids that consist of a carboxylic acid substituted with a hydroxyl group on the adjacent carbon. Lactic, citric, and malic acid are in this category, which have been used in food, beverage, and animal nutrition [11]. Tartaric acid is frequently used as an acidulant. Tartaric acid as a hydroxy acid is the most water-soluble of the solid acidulants and has a strong tart taste and enhances grape-like flavors particularly grape and lime. It naturally exists in fruits such as grapes and pineapples [9].

For some hydrocolloids with the involvement of ions, temperature change, pH change, or addition of other solutes, the interactions between polymer segments are dominant and could induce gelation when ordered molecular structures, e.g. junction zones, are formed [12]. pH is an important parameter that affects the rheological properties of hydrocolloid solutions. The addition of acid to an aqueous xanthan gum solution and changes in pH also affect the viscosity of this solution [5]. Hayta et al. [5] examined the impact of pH on a dispersion of galactomannan–xanthan gum mixtures. An apparent viscosity-enhancing effect was clearly observed for the sample solutions in the range of pH 2- 6, and the values of consistency coefficient gradually reduced at pH 2. Medina-Torres et al. [13] reported that the viscosity of *Opuntia ficus indica* gum reaches a constant value in the basic range and that the viscosity of gum decreases sharply when the pH value decreases from 7 to 2. The *in vitro* viscosity of guar gum, pectin, and CMC were studied by Brenelli et al. [14]. Their results show that the processes of acidification, alkalinization, and exposure to intestinal ions lead to various viscosity changes in the gums with similar initial viscosity, with a direct correlation between the slight decrease in gums viscosity *in vitro*. In Ozgur et al. [1] study, the flow properties of a ternary gum system (xanthan, CMC, and pectin) were examined in a model system made with an organic acid (citric or tartaric acid) and sucrose. Their results showed that CMC had the highest consistency coefficient among the gums compared to xanthan gum and pectin in the citric acid–sucrose and tartaric acid–sucrose model systems. The effect of organic acids on the viscosity and rheological behavior of guar gum solution was examined by Salehi et al. [15]. The results showed that the sample containing 1 % tartaric acid had the lowest consistency coefficient and the sample containing 0.5 % ascorbic acid had the highest consistency coefficient. Also, the flow behavior index of the guar gum solution increased when the acid concentration was increased.

The study of rheological properties is important when polysaccharide gums are used as a food additives, especially in food preparation which involves certain rheological properties, for instance as stabilizer and thickener [16, 17]. The study of the stability of gum solutions in acidic environments is of great importance for the study of functional properties in food processing and more recently for those interested in the physiological effects of dietary fibre [18]. In this study, we investigated how the addition of edible organic acids (ascorbic acid, citric acid, malic acid, and tartaric acid) to WSSG dispersions affects viscosity and rheological properties.

2. Materials and methods

2.1. Production of acid solutions containing gum

For the current study, wild sage seeds (also known as *Salvia macrosiphon* L.) were checked and any dirt or other unwanted items were removed during the cleaning process. Then, the seeds were put in water for 20 minutes at a temperature of 25°C, using 1 part of the seeds for every 20 parts of water [7]. The WSSG was taken out from the seeds by using a machine called an extractor (FJ-479, Tulips, Iran). This machine has a rotating disc that scrapes the gum off the surface of the seeds. The dispersion was dehydrated in an oven (Shimaz, Iran) with air blowing at 60°C and then the gum powder was ground, packaged, and stored in a cool, dry place.

Organic acids including ascorbic acid, citric acid, malic acid, and tartaric acid were purchased in powder form (China) and dissolved in distilled water. Two concentrations of each acid, 0.5% and 1%, were prepared, and the distilled water sample was considered as the control sample (0% acid). The WSSG solutions were provided by solving the gum powder (0.20%, w/v) in distilled water [19] and different concentrations of ascorbic acid, citric acid, malic acid, and tartaric acid solutions using a magnetic stirrer.

2.2. Apparent viscosity

The apparent viscosity of WSSG dispersions was measured using a viscometer (Brookfield, DV2T, RV, USA) at 20°C. An example of the process for preparing acid solution containing WSSG and measuring the apparent viscosity and flow behavior index of the dispersion is shown in Figure 1. The apparent viscosity and shear stress (SS) of WSSG dispersion at various shear rates (12.2-171.2 s^{-1}) were measured using an UL Adapter Kit.

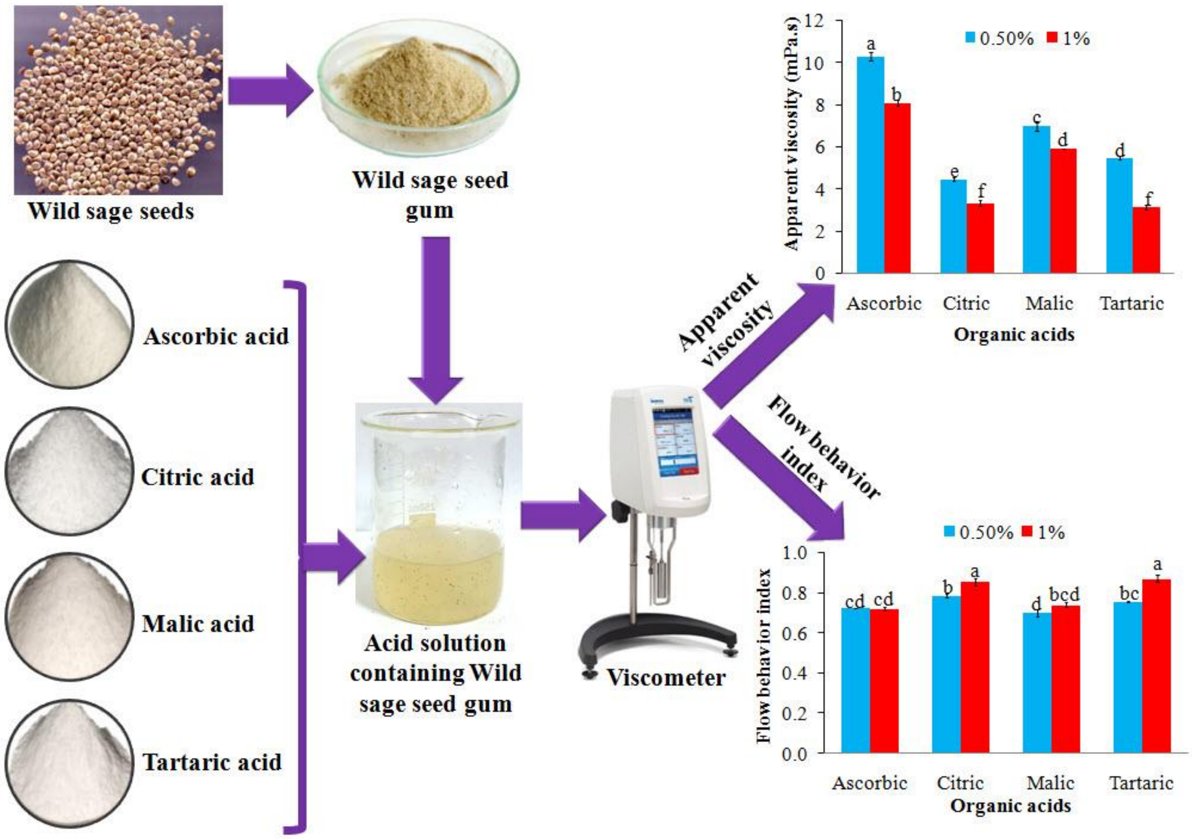

Fig. 1. Schematic of the process for preparing acid solution containing Wild sage seed gum and measuring the apparent viscosity and flow behavior index of the dispersion.

2.3. Mathematical modeling

Power law, Bingham, Herschel-Bulkley (HB), and Casson models are common ways of representing the behavior of several gum dispersions [7]. In this research, these models were used to match the SS and shear rates (SR) results of the WSSG dispersions containing edible organic acids. The experimental results were correlated for ease of use in rheological studies while maintaining appropriate accuracy using the function cftool (Curve Fitting Tool) in Matlab software (version R2012a).

2.4. Statistical analysis

The analysis was performed in triplicate. The obtained results were presented as the mean with standard deviation (SD). Differences between means were established using Duncan's multiple range using SPSS (version 21) for Windows. Mean differences were considered notably at the $p<0.05$ level.

3. Results and discussion

3.1. Apparent viscosity

As functional ingredients, hydrocolloids or gums are used to control the rheology and textural properties of foods, and as fat and sugar replacers due to their high fiber content [20]. Figure 2 displays how the viscosity of WSSG dispersion change when the shear is applied at different speeds. It can be seen that the apparent viscosity of WSSG dispersion become less when it is stirred faster (shear-thinning behavior). In this study, the apparent viscosity of the sample containing 0.5% ascorbic acid reduced from 17.1 mPa.s to 7.1 mPa.s with the SR increased from 12.2 s^{-1} to 171.2 s^{-1}.

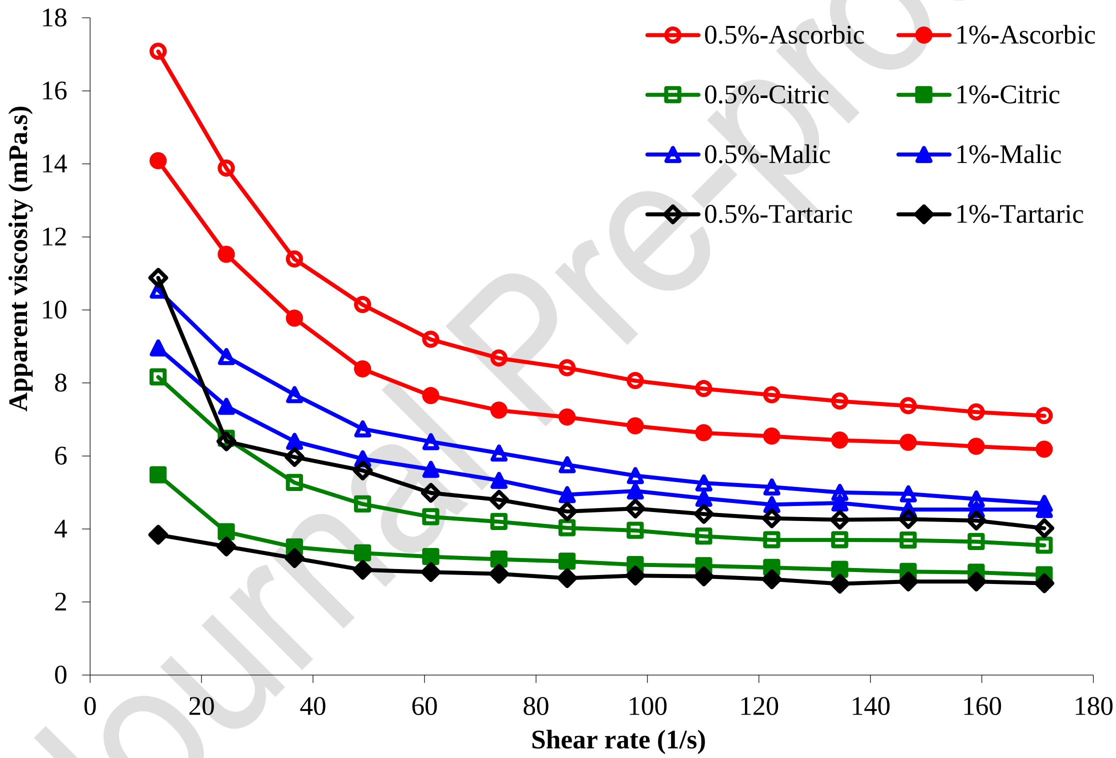

Fig. 2. Impact of shear rate on the apparent viscosity of Wild sage seed gum dispersion containing edible organic acids.

Organic acids are essential components of food that determine the food flavor. Various organic acids are present in foods, and the amount of any acid has a significant effect on the taste and aroma of the food [21]. In this study, the apparent viscosity of the control sample (0% acid) was 32.29 ± 0.42 mPa.s at the SR of 49 s^{-1} and 20°C (Figure 3). The apparent viscosity values of the WSSG dispersions prepared in organic acids model system (0.5 %) were determined to be 10.31, 4.48, 7.00, and 5.49 mPa.s for ascorbic, citric, malic, and tartaric acids, respectively, at the SR of 49 s^{-1} and 20°C. The apparent viscosity of the WSSG dispersions reduced as the organic acids concentration increased from 0.5% to 1%. This behavior was observed for all organic acids. The highest decrease in viscosity was related to 1% tartaric acid or citric acid and the lowest was related to 0.5% ascorbic acid. The results show that when the ascorbic acid concentration increased from 0.5% to 1%, the apparent viscosity of the WSSG dispersion significantly reduced from 10.31 mPa.s to 8.07 mPa.s (SR=49 s^{-1}). This is in agreement with data reported in the field, where the viscosity of fully hydrated guar gum solutions was slightly lower at acidic pH than at neutral pH, even in the absence of degradation [18].

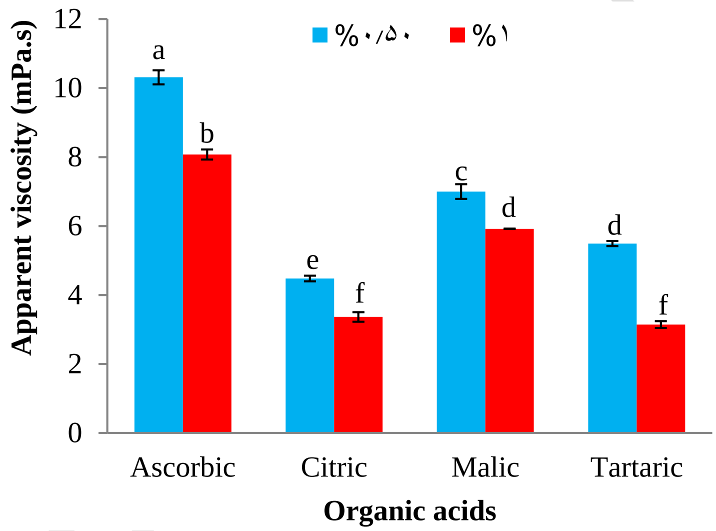

Fig. 3. Impact of organic acids on the apparent viscosity of Wild sage seed gum dispersion (shear rate=49).

Error bars represent the SD of the mean of three replicates. Different letters above column indicate significant differences between dispersions ($p<0.05$).

3.2. Power law model

The study of rheological properties is important for the design of different processes (such as fluid flow, pumps, processes of extraction, filtration, purification, pasteurization, evaporation, drying) [16]. Due to the importance of rheological characterization and modeling of food formulations, the number of scientific studies published on this subject has increased significantly in the recent years [22]. In the current study, the experimental data (shear stress–shear rate) were fitted according to the Power law, Bingham, Herschel–Bulkley and Casson models [23]. The Power law model showed appropriate performance with the high r-value (> 0.9946) and the low sum of squared error (SSE) values (< 0.0062) and root mean square error (RMSE) values (< 0.0227) for all dispersions containing edible organic acids (Table 1). In this study, the k and n values of the control sample were 0.174 ± 0.003 $Pa.s^n$ and 0.568 ± 0.006, respectively. It was observed that the addition of organic acids had a significant influence on the rheological parameters of solutions. The impact of organic acids on the consistency coefficient of WSSG dispersion is reported in Figure 4. The consistency coefficient of the samples reduced when the acid percent was increased. The sample containing 1% tartaric acid or citric acid had the lowest consistency coefficient and the sample containing 0.5% ascorbic acid had the highest consistency coefficient. The results show that when the malic acid concentration increased from 0.5% to 1%, the consistency coefficient of the WSSG dispersion reduced from 0.023 $Pa.s^n$ to 0.014 $Pa.s^n$ ($p<0.05$). Wang et al. [18] studied the stability of guar gum in an aqueous systems under acidic conditions at temperatures of 25, 37, and 50°C. The results of this study show that guar gum is relatively stable under mild acidic conditions, and higher temperatures and lower pH values decrease the stability of guar gum in solution.

Table 1- Values of statistical parameters of the Power law model for estimating shear stress data

Organic acid	Acid concentration	Sum of squared error (SSE)	Correlation coefficient (r)	Root mean square error (RMSE)
Control	0%	0.0048	0.9997	0.0198
Ascorbic	0.5%	0.0057	0.9981	0.0218
Citric		0.0015	0.9985	0.0110
Malic		0.0009	0.9993	0.0083
Tartaric		0.0028	0.9969	0.0153
Ascorbic	1%	0.0037	0.9979	0.0173
Citric		0.0006	0.9989	0.0071
Malic		0.0016	0.9984	0.0112
Tartaric		0.0013	0.9968	0.0099

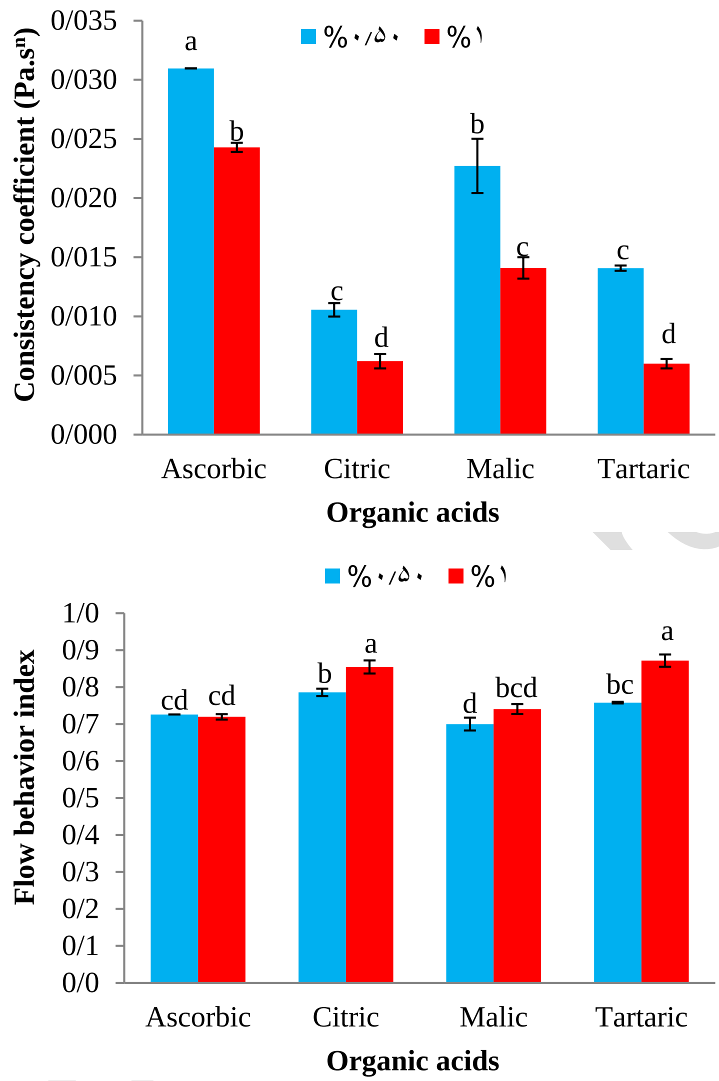

Fig. 4. Impact of organic acids on the consistency coefficient and flow behavior index of Wild sage seed gum dispersion (Power law model).

Error bars represent the SD of the mean of three replicates. Different letters above column indicate significant differences between dispersions ($p<0.05$).

Tartaric acid and its products are used for flavor enhancement, preservation, pH regulation and chelating as well as humectants, firming agents, baking additives, and emulsifiers [24]. The Power law equation shows that a fluid with shear-thinning behavior has a value of n less than 1 [25]. The impact of organic acids on the flow behavior index of WSSG dispersion is reported in Figure 4. The flow behavior index of the samples increased when the acid concentration was increased (decreases in shear-thinning behavior). The sample containing 1% tartaric acid had the highest flow behavior index and the sample containing 0.5% malic acid had the lowest flow behavior index. The results show that when the citric acid concentration increased from 0.5% to 1%, the flow behavior index of the WSSG dispersion significantly enhanced from 0.786 to 0.855 ($p<0.05$). The alteration within the consistency coefficient and flow behavior index of the WSSG dispersion may be due to the structural changes of the gum in the presence of different acids.

3.3. Bingham model

The experimental values of SS versus SR for WSSG dispersion containing edible organic acids were fitted to the Bingham model and the constant coefficients of this equation were calculated. The mean values of SSE, r, and RMSE for WSSG dispersions were between 0.0003 and 0.1295, 0.9920 and 0.9995, and 0.0049 and 0.1039, respectively Table 2.

Table 2- Values of statistical parameters of the Bingham model for estimating shear stress data

Organic acid	Acid concentration	Sum of squared error (SSE)	Correlation coefficient (r)	Root mean square error (RMSE)
Control	0%	0.1212	0.9923	0.1005
Ascorbic	0.5%	0.0053	0.9983	0.0209
Citric		0.0008	0.9989	0.0078
Malic		0.0051	0.9959	0.0194
Tartaric		0.0012	0.9986	0.0101
Ascorbic	1%	0.0036	0.9979	0.0170
Citric		0.0003	0.9993	0.0054
Malic		0.0025	0.9975	0.0142
Tartaric		0.0012	0.9970	0.0097

The current study shows that the Bingham yield stress (τ_{0B}) and Bingham plastic viscosity (η_B) of the control sample were 0.781 ± 0.007 Pa and 0.015 ± 0.0002 Pa.s, respectively. The impact of organic acids on the Bingham yield stress parameter of WSSG dispersion is reported in Figure 5. The Bingham yield stress of the samples reduced when acids percent was increased. The dispersion containing 1% tartaric acid had the lowest yield stress (0.034 Pa) and the sample containing 0.5% ascorbic acid had the highest yield stress (0.180 Pa). The results show that when the citric acid percent increased from 0.5% to 1%, the Bingham yield stress of the WSSG dispersion significantly decreased from 0.064 Pa to 0.035 Pa ($p<0.05$).

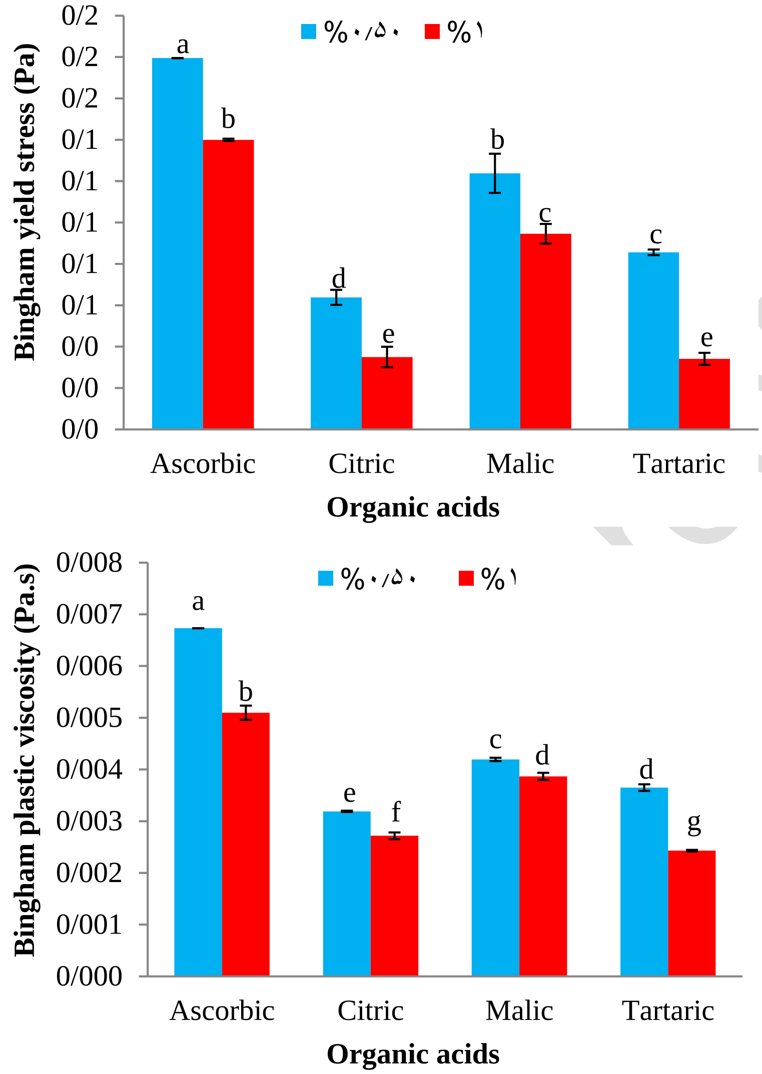

Fig. 5. Impact of organic acids on the Bingham yield stress and Bingham plastic viscosity parameters of Wild sage seed gum dispersion (Bingham model).

Error bars represent the SD of the mean of three replicates. Different letters above column indicate significant differences between dispersions ($p<0.05$).

Figure 5 shows the impact of organic acids on the Bingham plastic viscosity of WSSG dispersions. The plastic viscosity of the samples reduced when acids percent was increased. The dispersion containing 1% tartaric acid had the lowest plastic viscosity (0.0024 Pa.s) and the sample containing 0.5% ascorbic acid had the highest plastic viscosity (0.0067 Pa.s). The results show that when the ascorbic acid concentration increased from 0.5 to 1%, the Bingham plastic viscosity of the WSSG dispersion significantly reduced from 0.0067 Pa.s to 0.0051 Pa.s ($p<0.05$).

3.4. Herschel-Bulkley (HB) model

For the past three decades, hydrocolloids have been increasingly used in various food formulations for two main reasons. The first reason is their physical functionality, which refers to their ability to modify the chemical conformation and structure of the polymers in a solution or system to achieve desired rheological characteristics and food structure [12]. The experimental values of SS versus SR for WSSG dispersion were fitted to the HB model and the constant coefficients of this equation were calculated. Mean values of SSE, r, and RMSE for WSSG dispersion ranged from 0.0002-0.0055, 0.9956-0.9998, and 0.0039-0.0223, respectively Table 3. Based on the HB model, all WSSG dispersions demonstrated shear-thinning behavior, described by the flow behavior index (n_H) lower than 0.998 (Figure 6). The results of the HB model showed that the values of the yield stress were between 2.30×10^{-6} Pa and 1.27×10^{-1} Pa.

Table 3- Values of statistical parameters of the Herschel-Bulkley model for estimating shear stress data

Organic acid	Acid concentration	Sum of squared error (SSE)	Correlation coefficient (r)	Root mean square error (RMSE)
Control	0%	0.0036	0.9998	0.0177
Ascorbic	0.5%	0.0022	0.9993	0.0139
Citric		0.0007	0.9991	0.0075
Malic		0.0006	0.9995	0.0072
Tartaric		0.0011	0.9988	0.0100
Ascorbic	1%	0.0017	0.9990	0.0125
Citric		0.0003	0.9995	0.0049
Malic		0.0012	0.9988	0.0098
Tartaric		0.0011	0.9972	0.0095

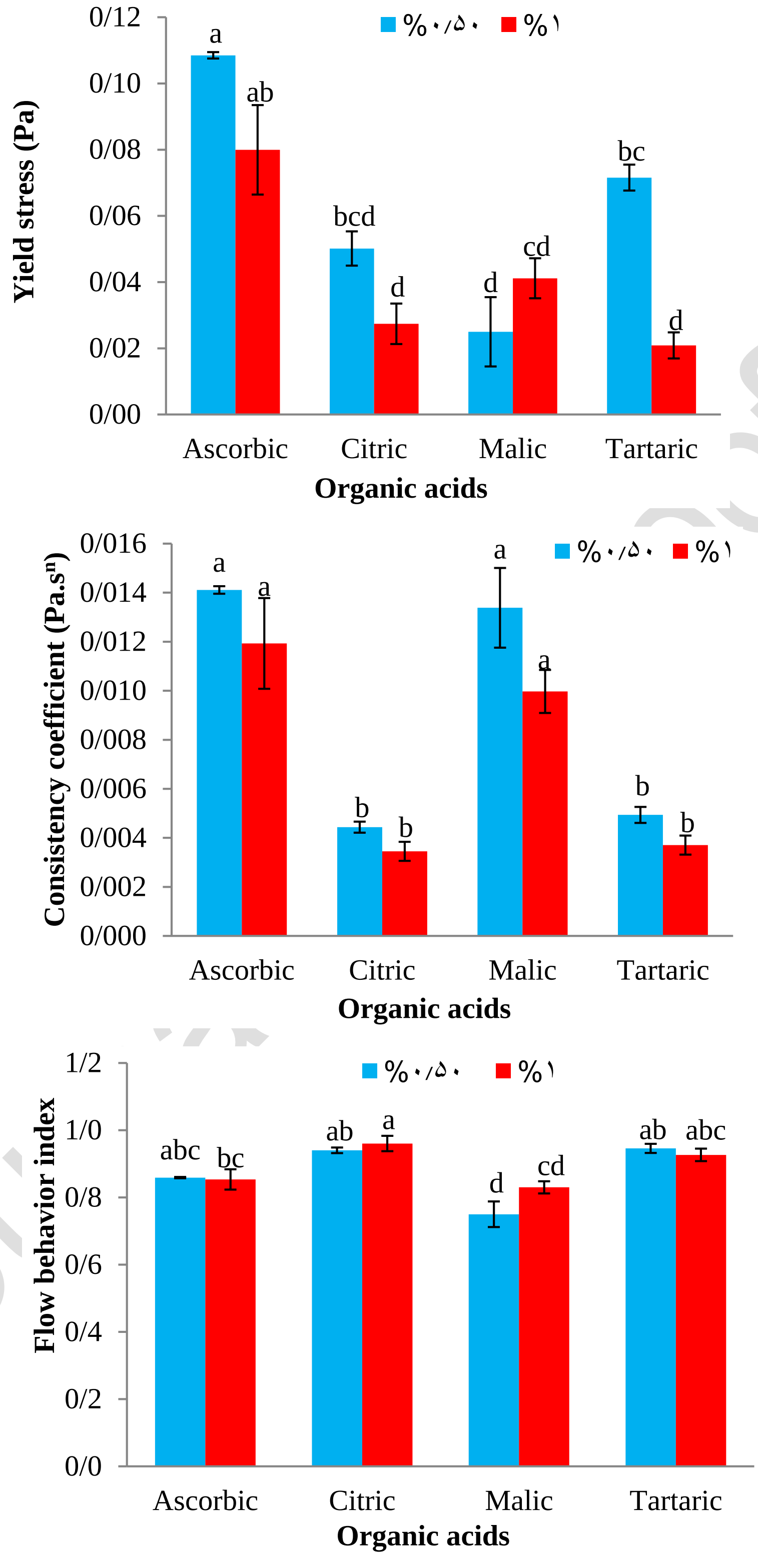

Fig. 6. Impact of organic acids on the yield stress, consistency coefficient, and flow behavior index parameters of Wild sage seed gum dispersion (Herschel-Bulkley model).
Error bars represent the SD of the mean of three replicates. Different letters above column indicate significant differences between dispersions ($p<0.05$).

The flow behavior and thickening properties of gums in solution can be considerably affected by variables such as shear rate and time, compound concentration, temperature, and pH, etc. Analyzing the individual or combined effects of these factors is important, especially when they are used for food texture modification and process design, evaluation, and modeling [16]. So, a number of studies have been carried out to analyze the rheological characteristics of hydrocolloids individually or as ingredients of food formulations [7, 15-17, 19]. In this study, the yield stress, consistency coefficient, and flow behavior index (HB model) of the control sample were 0.109 ± 0.019 Pa, 0.141 ± 0.003 Pa.s^n and 0.603 ± 0.003, respectively. The impact of organic acids on the consistency coefficient of WSSG dispersion is reported in Figure 6. The consistency coefficient of the samples reduced when acids percent was increased. The results show that when the ascorbic acid concentration increased from 0.5% to 1%, the consistency coefficient of the WSSG dispersion reduced from 0.014 Pa.s^n to 0.012 Pa.s^n (p>0.05). The sample containing 1% citric acid had the lowest consistency coefficient and the sample containing 0.5% ascorbic acid had the highest consistency coefficient.

The impact of organic acids on the flow behavior index (HB model) of WSSG dispersion is reported in Figure 6. The flow behavior index of the samples increased when citric and malic acids concentration was increased (decreases in shear-thinning behavior). The sample containing 0.5% malic acid had the lowest flow behavior index (0.750) and the sample containing 1% citric acid had the highest flow behavior index (0.960). The results show that when the malic acid percent increased from 0.5% to 1%, the flow behavior index of the WSSG dispersion increased from 0.750 to 0.830 (p>0.05) (decreases in shear-thinning behavior).

3.5. Casson model

The experimental values of SS versus SR for WSSG dispersion containing edible organic acids were fitted to the Casson model and the constant coefficients of this equation were calculated. The relationship between shear stress and shear rate also fits well with the Casson's equation. Mean values of SSE, r, and RMSE for WSSG dispersion were between 0.0002 and 0.0325, 0.9954 and 0.9996, and 0.0041 and 0.0520, respectively (Table 4).

Table 4- Values of statistical parameters of the Casson model for estimating shear stress data

Organic acid	Acid concentration	Sum of squared error (SSE)	Correlation coefficient (r)	Root mean square error (RMSE)
Control	0%	0.0275	0.9982	0.0478
Ascorbic	0.5%	0.0019	0.9993	0.0123
Citric		0.0008	0.9989	0.0080
Malic		0.0016	0.9987	0.0105
Tartaric		0.0014	0.9984	0.0109
Ascorbic	1%	0.0019	0.9989	0.0126
Citric		0.0004	0.9992	0.0056
Malic		0.0012	0.9988	0.0097
Tartaric		0.0012	0.9972	0.0092

Casson yield stress is the smallest stress that is needed for the fluid to flow [26]. In the current work, the Casson yield stress (τ_{0c}) and Casson plastic viscosity (η_c) of the control sample were 0.354 ± 0.007 Pa and 0.093 ± 0.001 Pa.s, respectively. The impact of organic acids on the Casson yield stress of WSSG dispersion is reported in Figure 7. The Casson yield stress of the samples reduced when acids percent was increased. The dispersion containing 1% citric acid had the lowest yield stress (0.006 Pa) and the sample containing 0.5% ascorbic acid had the highest yield stress (0.055 Pa). The results show that when the malic acid concentration increased from 0.5% to 1%, the Casson yield stress of the WSSG dispersion significantly reduced from 0.041 Pa to 0.027 Pa ($p<0.05$).

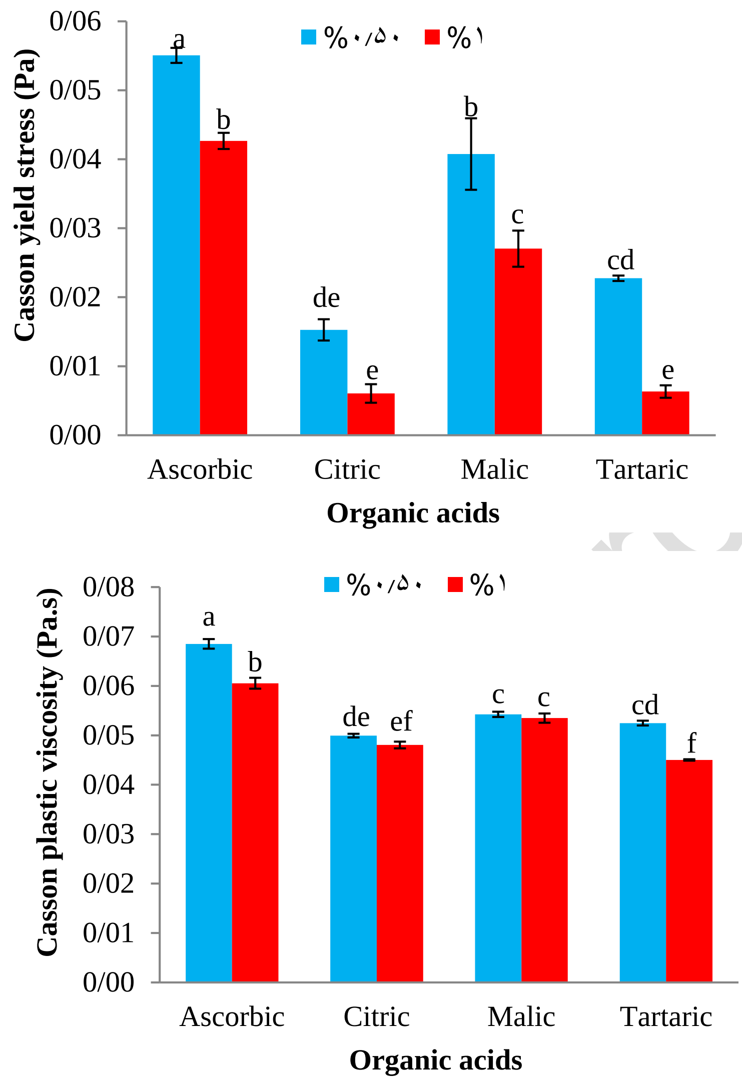

Fig. 7. Impact of organic acids on the Casson yield stress and Casson plastic viscosity parameters of Wild sage seed gum dispersion (Casson model).

Error bars represent the SD of the mean of three replicates. Different letters above column indicate significant differences between dispersions ($p<0.05$).

In addition, the impact of organic acids on the Casson plastic viscosity of WSSG dispersion is reported in Figure 7. The plastic viscosity of the samples decreased when acids concentration was increased. The dispersion containing 1% tartaric acid had the lowest plastic viscosity (0.045 Pa.s) and the sample containing 0.5% ascorbic acid had the highest plastic viscosity (0.068 Pa.s). The results show that when the tartaric acid concentration increased from 0.5% to 1%, the Casson plastic viscosity of the WSSG dispersion significantly reduced from 0.052 Pa.s to 0.045 Pa.s ($p<0.05$).

4. Conclusion

Different types of gums are utilized in different kinds of food products like beverages, sauces, dairy products, instant foods, ready-to-use dessert soups, bakery products, and confectionaries. Addition of edible organic acids such as malic, citric, ascorbic, and tartaric is commonly used for pH control in a number of food products. So, in the current work, the edible organic acids (ascorbic, citric, malic, and tartaric) at two concentrations (0.5, and 1 %) on the viscosity and rheological parameters of WSSG dispersion were investigated. The finding of this study revealed that the apparent viscosity of WSSG dispersions reduced the SR increased (shear-thinning behavior). As selected organic acids percent increased, the viscosity of the solutions decreased, and the greatest decrease in viscosity was due to tartaric and citric acids. Based on the values of correlation coefficients (r) and errors (SSE and RMSE) of the estimated parameters, HB model was chosen for fitting of experimental data of WSSG dispersions. The consistency coefficients (Power law and HB models) of the samples reduced when acids percent was increased. But, the flow behavior index (Power law model) of the samples increased when selected organic acids percent was increased. Based on the results of this research, the use of WSSG in food products containing high concentrations of tartaric and citric acids is not recommended.

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References

[1] Ozgur, A., Dogan, M., & Karaman, S. (2017). Rheological interactions of the xanthan gum and carboxymethyl cellulose as alternative to pectin in organic acid–sucrose model system: simplex lattice mixture design approach. *Eur. Food Res. Technol.*, 243, 1041-1056. doi: 10.1007/s00217-016-2809-7
[2] Salehi, F. (2020). Effect of common and new gums on the quality, physical, and textural properties of bakery products: A review. *J. Texture Stud.*, 51, 361-370. doi: 10.1111/jtxs.12482
[3] Kang, J., Yue, H., Li, X., He, C., Li, Q., Cheng, L., Zhang, J., Liu, Y., Wang, S., & Guo, Q. (2023). Structural, rheological and functional properties of ultrasonic treated xanthan gums. *Int. J. Biol. Macromol.*, 246, 125650. doi: 10.1016/j.ijbiomac.2023.125650
[4] Nor Hayati, I., Wai Ching, C., & Rozaini, M.Z.H. (2016). Flow properties of o/w emulsions as affected by xanthan gum, guar gum and carboxymethyl cellulose interactions studied by a mixture regression modelling. *Food Hydrocolloid*, 53, 199-208. doi: 10.1016/j.foodhyd.2015.04.032
[5] Hayta, M., Dogan, M., & Aslan Türker, D. (2020). Rheology and microstructure of galactomannan–xanthan gum systems at different pH values. *J. Food Process Eng.*, 43, e13573. doi: 10.1111/jfpe.13573
[6] Salehi, F., Haseli, A., & Roustaei, A. (2022). Coating of zucchini slices with Balangu, Basil, and Wild sage seeds gums to improve the frying properties. *Eur. J. Lipid Sci. Technol.*, 124, 2100120. doi: 10.1002/ejlt.202100120
[7] Salehi, F., & Inanloodoghouz, M. (2023). Rheological properties and color indexes of ultrasonic treated aqueous solutions of basil, Lallemantia, and wild sage gums. *Int. J. Biol. Macromol.*, 253, 127828. doi: 10.1016/j.ijbiomac.2023.127828
[8] Razavi, S.M.A., Cui, S.W., Guo, Q., & Ding, H. (2014). Some physicochemical properties of sage (*Salvia macrosiphon*) seed gum. *Food Hydrocolloid*, 35, 453-462. doi: 10.1016/j.foodhyd.2013.06.022
[9] Chahardoli, A., Jalilian, F., Memariani, Z., Farzaei, M.H., & Shokoohinia, Y. (2020) Chapter 26 - Analysis of organic acids, in: A. Sanches Silva, S.F. Nabavi, M. Saeedi, S.M. Nabavi (Eds.) Recent advances in natural products analysis, Elsevier, pp. 767-823.
[10] Wang, J., Wu, Z., & Wang, H. (2022). Combination of ultrasound-peracetic acid washing and ultrasound-assisted aerosolized ascorbic acid: A novel rinsing-free disinfection method that improves the antibacterial and antioxidant activities in cherry tomato. *Ultrason. Sonochem.*, 86, 106001. doi: 10.1016/j.ultsonch.2022.106001
[11] Anyasi, T.A., Jideani, A.I.O., & McHau, G.R.A. (2015). Effect of organic acid pretreatment on some physical, functional and antioxidant properties of flour obtained from three unripe banana cultivars. *Food Chem.*, 172, 515-522. doi: 10.1016/j.foodchem.2014.09.120
[12] Goff, H.D., & Guo, Q. (2019) The role of hydrocolloids in the development of food structure, in: F. Spyropoulos, A. Lazidis, I. Norton (Eds.) Handbook of Food Structure Development, The Royal Society of Chemistry, pp. 1-28.

[13] Medina-Torres, L., Brito-De La Fuente, E., Torrestiana-Sanchez, B., & Katthain, R. (2000). Rheological properties of the mucilage gum (*Opuntia ficus indica*). *Food Hydrocolloid*, 14, 417-424. doi: 10.1016/S0268-005X(00)00015-1
[14] Brenelli, S., Campos, S., & Saad, M. (1997). Viscosity of gums in vitro and their ability to reduce postprandial hyperglycemia in normal subjects. *Braz. J. Med. Biol. Res.*, 30, 1437-1440. doi: 10.1590/S0100-879X1997001200009
[15] Salehi, F., Samary, K., & Tashakori, M. (2024). Influence of organic acids on the viscosity and rheological behavior of guar gum solution. *Results Eng.*, 22, 102307. doi: 10.1016/j.rineng.2024.102307
[16] Capitani, M.I., Corzo-Rios, L.J., Chel-Guerrero, L.A., Betancur-Ancona, D.A., Nolasco, S.M., & Tomás, M.C. (2015). Rheological properties of aqueous dispersions of chia (*Salvia hispanica* L.) mucilage. *J. Food Eng.*, 149, 70-77. doi: 10.1016/j.jfoodeng.2014.09.043
[17] Safdar, B., Pang, Z., Liu, X., Rashid, M.T., & Jatoi, M.A. (2023). Structural characterization, physicochemical and rheological characteristics of flaxseed gum in comparison with gum Arabic and xanthan gum. *J. Food Meas. Charact.*, 17, 2193-2203. doi: 10.1007/s11694-022-01750-2
[18] Wang, Q., Ellis, P.R., & Ross-Murphy, S.B. (2000). The stability of guar gum in an aqueous system under acidic conditions. *Food Hydrocolloid*, 14, 129-134. doi: 10.1016/S0268-005X(99)00058-2
[19] Salehi, F., & Inanloodoghouz, M. (2024). Effects of ultrasonic intensity and time on rheological properties of different concentrations of xanthan gum solution. *Int. J. Biol. Macromol.*, 263, 130456. doi: 10.1016/j.ijbiomac.2024.130456
[20] Jo, W., Bak, J.H., & Yoo, B. (2018). Rheological characterizations of concentrated binary gum mixtures with xanthan gum and galactomannans. *Int. J. Biol. Macromol.*, 114, 263-269. doi: 10.1016/j.ijbiomac.2018.03.105
[21] Duan, W., Huang, Y., Xiao, J., Zhang, Y., & Tang, Y. (2020). Determination of free amino acids, organic acids, and nucleotides in 29 elegant spices. *Food Sci. Nutr.*, 8, 3777-3792. doi: 10.1002/fsn3.1667
[22] Kechinski, C.P., Schumacher, A.B., Marczak, L.D.F., Tessaro, I.C., & Cardozo, N.S.M. (2011). Rheological behavior of blueberry (*Vaccinium ashei*) purees containing xanthan gum and fructose as ingredients. *Food Hydrocolloid*, 25, 299-306. doi: 10.1016/j.foodhyd.2010.06.007
[23] Salehi, F., Tashakori, M., & Samary, K. (2024). Comparison of four rheological models for estimating viscosity and rheological parameters of microwave treated Basil seed gum. *Scientific Reports*, 14, 15493. doi: 10.1038/s41598-024-66690-x
[24] Smith, J., & Hong-Shum, L. (2003) Tartaric Acid, in: Food Additives Data Book, pp. 70-74.
[25] Kumar, Y., Roy, S., Devra, A., Dhiman, A., & Prabhakar, P.K. (2021). Ultrasonication of mayonnaise formulated with xanthan and guar gums: Rheological modeling, effects on optical properties and emulsion stability. *LWT*, 149, 111632. doi: 10.1016/j.lwt.2021.111632
[26] Li, X., Fang, Y., Zhang, H., Nishinari, K., Al-Assaf, S., & Phillips, G.O. (2011). Rheological properties of gum arabic solution: From Newtonianism to thixotropy. *Food Hydrocolloid*, 25, 293-298. doi: 10.1016/j.foodhyd.2010.06.006

ویژگی‌های رئولوژیکی محلول صمغ دانه مرو: تأثیر غلظت‌های مختلف اسید آسکوربیک، اسید سیتریک، اسید مالیک و اسید تارتاریک

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چکیده

در این مطالعه تأثیر اسیدهای آلی خوراکی در دو غلظت بر ویسکوزیته و رفتار رئولوژیکی محلول صمغ دانه مرو بررسی شد. مقادیر ویسکوزیته ظاهری محلول صمغ دانه مرو تهیه‌شده در سیستم مدل اسیدهای آلی (۰/۵٪) برای اسیدهای آسکوربیک، سیتریک، مالیک و تارتاریک در سرعت برشی برابر ۴۹ بر ثانیه و در ۲۰ درجه سلسیوس به ترتیب برابر ۱۰/۳۱، ۴/۴۸، ۷/۰۰ و ۵/۴۹ میلی پاسکال ثانیه تعیین شد. ویسکوزیته ظاهری محلول صمغ دانه مرو با افزایش غلظت اسیدهای آلی از ۰/۵ به ۱ درصد کاهش یافت. بیشترین کاهش ویسکوزیته مربوط به اسیدهای تارتاریک و سیتریک ۱ درصد و کمترین آن مربوط به اسید آسکوربیک ۰/۵ درصد بود. معادله هرشل بالکلی بهترین مدل برای توصیف رفتار محلول صمغ دانه مرو حاوی اسیدهای آلی خوراکی بود. این مدل با حداکثر ضریب تبیین (۰/۹۹۵۶<) و حداقل مقادیر خطا عملکرد خوبی از خود نشان داد. مقادیر ضریب قوام نمونه‌ها (مدل‌های قانون توان و هرشل بالکلی) با افزایش درصد اسید کاهش یافت. نمونه حاوی ۱٪ اسید تارتاریک کمترین مقدار ضریب قوام و نمونه حاوی ۰/۵٪ اسید آسکوربیک دارای بیشترین مقدار ضریب قوام بود. با افزایش غلظت اسید، شاخص رفتار جریان نمونه‌ها افزایش یافت.

کلمات کلیدی: دانه مرو، شاخص رفتار جریان، ضریب قوام، هرشل بالکلی.

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