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Research article

Bi-polymeric structured system (xanthan gum-carboxymethyl cellulose) for developing instant powder with the ability to suspend flixweed seeds in beverages: Effect of pH and sweetener type

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ABSTRACT

Creating innovation in the production of beverage products has always been one of the goals of this industry. This investigation studied the fabrication of an instant biopolymeric structured powder to suspend flixweed seeds in a beverage. A mixture of carboxymethyl cellulose (CMC) and xanthan (XG) hydrocolloids in different ratios (CMC at 0.17–0.20 and xanthan XG at 0–0.03) and pH (4.0, 6.5, and 9.0) with sucrose sugar were used to create the instant structured system. Then, the best-structured system in neutral pH was studied along with different sweetener (sucrose, stevia and xylitol). The suspending environment had shear thinning behavior. The viscosity and yield stress of the samples increased by increasing xanthan concentration. pH of the environment had no significant effect on the rheological properties of the solutions ($P > 0.05$). However, it affected the formation time of the suspending system. The highest percentage of stable suspended seeds and the lowest fractal dimension change during storage time confirmed the samples containing 0.17 % CMC-0.03 % XG had the highest stability. The sensory results also confirmed that increasing the level of XG increased appearance attractiveness score. The low-calorie sweeteners significantly affected the rheological behavior and stability of the suspension system ($p < 0.05$). The shortest formation time of the structured system was observed in the presence of sucrose. The xylitol samples had the lowest stability and overall acceptance. The results of this study confirm the suitability of the CMC-XG suspending system to be applied for the rapid suspension of various particles.

1. Introduction

Flixweed (*Descurainia sophia* L.) is an annual herb from the Cruciferae family. It has distinguishable differences in seed size (oblong, 1.0–1.5 mm long) and color (orange-brown, light orange). Flixweed seeds contain various health-benefiting compounds known as 'nutraceuticals' and are used as herbal medicines because of its chemical profile. In Iran, its weed, known as khak-e shir or khakshir, is

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used with water as a beverage and as a thirst quencher in hot weather [1]. Flixweed is used as a source of foods and beverages. Previous studies reported anti-inflammatory activity, anthelmintic, antioxidant and radical scavenging, respiratory health promotion, analgesic, and anti-inflammatory as well as antipyretic effects [2].

Despite the health benefits, the food industry has not widely embraced the use of flixweed seeds due to their instability in beverages, causing precipitation of the seeds [1]. To address this, it is important to find solutions to enhance the quality and performance of flixweed products, especially given the growing consumer interest in healthy and nutritious beverages.

Traditional beverages typically suspend plant seeds within their structures. Additives such as xanthan gum or carrageenan are used to aid in the suspension and distribution of seeds, improving the appearance and beverage ability of the product. These natural additives have the ability to form a network, effectively trapping the flixweed seeds in water, resulting in a smooth texture and good mouth feel.

Furthermore, hydrocolloids, such as xanthan gum and carrageenan, are commonly used in food formulations to modify product properties, acting as thickeners, stabilizers, or gelling agents, thereby improving product quality and shelf life [3].

Considering the benefits of producing food products in powder form, it may be possible to formulate flixweed beverages in powder form. However, the rehydration process of beverage powders is a critical factor that needs consideration. The use of components that can quickly rehydrate and create a structured network to suspend the flixweed seeds after entering cold water is essential.

Numerous studies have been conducted to stabilize beverages, focusing on the rapid creation of a structured system in water and the suspension of flixweed seeds [4–8]. The factors influencing the formation of an instant polymeric structured system include the selection of raw materials, catalysts, and favorable environmental conditions such as pH and temperature [9]. It is expected that various additives will have an impact on the textural properties of the instant structured system, potentially leading to the development of restructured products such as fruit-based gels [9].

In order to produce an instant polymeric structured system, a polymer mixture based on polysaccharides was used. Linear polysaccharides with highly ordered structures are mostly insoluble because they can form crystalline or partially crystalline structures due to strong intermolecular interactions. Polysaccharides with branched structures show better solubility because (1) the branched structure can weaken intermolecular interactions due to steric effects, and also (2) these molecules have a lower volume and critical concentration compared to linear polysaccharides of the same molecular weight. However, in terms of gelation ability, molecules with a high degree of branching prevent the formation of the junction region and, therefore, have a probability of a lower ability to form a gel. Carboxymethylcellulose (CMC) is soluble in cold and hot water [10,11].

CMC can be used as a flocculant, chelating agent, emulsifier, thickening agent, water retaining agent, sizing agent, film-forming material, etc. [12]. In addition, it can be used to stabilize juice by electrostatic repulsion. Stabilization with CMC provides more transparent water and a brighter appearance [13].

Xanthan gum (XG) forms a weak gel and improves mouthfeel. Therefore, it is widely used in healthy lifestyle beverages to understand the natural feeling of fruit juice [14]. Xanthan gum is an anionic polysaccharide with high molecular weight [15,16], causing an increased viscosity, which also brings a greater degree of sustainability to the final product. Xanthan gum presented positive characteristics such as maintenance of viscosity under temperature changes and pH changes [16]. XG has a high viscosity at a low shear rate, so it limits its use in food, especially beverages [15]. However, a mixture of XG and CMC can be a suitable alternative in beverages and prevent sedimentation [15].

In the production of beverages, like other food products, paying attention to the nutritional characteristics of the product is one of the most essential points to be considered by the producers. In recent years, the public has noticed the consumption of beverages with less sugar and calories. Using sucrose substitute sweeteners can increase the beverage's nutritional value and create more health benefits in the product. Stevia and xylitol are among the sweeteners widely used today [17,18]. In this study, several sweeteners, such as Stevia and xylitol, were proposed to replace sucrose in the beverages.

In previous studies try to stabilize flixweed seeds in ready to drink beverage [1]. This study aimed to develop an instant beverage powder containing flixweed seeds. To the best of our knowledge, there is not any scientific report on this subject; The present study firstly attempts to investigate the impact of different XG: CMC mass ratios, pH, and the types of sweetener on various characteristics such as time-dependent/independent rheological characteristics, formation time of instant structured system, suspension ability, and stability of instant polymeric structured (fractal dimension and …) of suspended flixweed seed beverage.

2. Materials and methods

2.1. Materials

Flixweed seeds were purchased from local stores in Mashhad, Iran. Xanthan gum and carboxymethyl cellulose were obtained from Fufeng Company in China. Stevia and xylitol were acquired from Foodmate in China and Miradent in Germany, respectively. All of the chemical materials were of analytical grade.

2.2. Preparation of instant structured system

Mixtures of CMC and XG were used to create instant structured systems. Initially, various ratios of CMC-XG (0.2–0.0 % (w/v), 0.19 % (w/v) - 0.01 % (w/v), 0.18 % (w/v)-0.02 % (w/v), and 0.17 % (w/v)-0.03 % (w/v)) at a consistent concentration of 0.2 % (w/v) were measured and combined with sucrose powder (12 % (w/v)). To investigate the characteristics of the structured system, the hydrocolloid and sucrose mixture were introduced into a water-based environment (distilled water), and the system's structural features were promptly assessed after stirring at a constant speed and time (150 rpm for 1 min). The structural properties of the suspending system were studied using different mixing ratios of CMC: XG (0.2:0.0, 0.19: 0.01, 0.18: 0.02 and 0.17: 0.03) and under acidic (pH 4.5), neutral (pH 6.0), and alkaline (pH 9.0) conditions. The seeds weight was about 10 % basis on water weight. The flixweed seeds characteristics were as follows: Weight: 0.0001515 g, density: 0.71904 g/ml, volume: 0.0002146 ml, moisture: 7.58 % dry basis, and length: 0.9 cm ~22 gr instant powders in sachets (hydrocolloid, flixweed seeds and sucrose mixture) dissolved in 200 cc of water to prepare the final drinking sample.

Then, the best condition (CMC-XG ratio and pH) was selected, and the impact of sweeteners on suspending system were investigated. To evaluate the impact of sweeteners on the formation and stability of the suspension system, samples containing 12 % (w/v) sucrose, 0.01–5.00 % stevia-sucrose (w/v), and 12 % (w/v) xylitol were prepared. The beverages were prepared using a specific ratio of CMC: XG at pH 6.

2.3. Rheological behavior

2.3.1. Time independent rheological properties

The flow behavior of samples with a shear rate of 0.1–100 s^{-1} was investigated by a viscometer (Brookfield, LV DVII Ultra, USA) at a temperature of 7 °C (Ulabo, Model F-12-MC, Germany). The rheological data (shear rate-shear stress) was fitted with power-law (Equation (1)) and Casson (Equation (2)) models to describe the rheological behavior

$$\tau = k_p \dot{\gamma}^{n_p} \tag{1}$$

where k is consistency coefficient ($Pa.s^n$) and n is flow behavior index (dimensionless).

$$\tau^{0.5} = k_{0c}^{0.5} + k_c(\dot{\gamma})^{0.5} \tag{2}$$

where k_C ($Pa^{0.5}.s^{0.5}$) and k_{0C} ($Pa^{0.5}$) are the constant of Casson model. $K_c^2 = \mu_c$ and $(k_{0c})^2 = \tau_{oc}$ are respectively Casson viscosity (Pa.s) and Casson yield stress (Pa).

2.3.2. Time dependent rheological properties

In evaluating time-dependent rheological properties, the samples were prepared and subjected to a constant shear rate of 100 s^{-1}, which is reported to be the effective shear rate in oral sensory evaluation for beverages at a temperature of 7 °C. The shear stress (τ) as a function of the shearing time (t) until reaching a constant stress value was recorded, and the time-dependent flow behavior of the

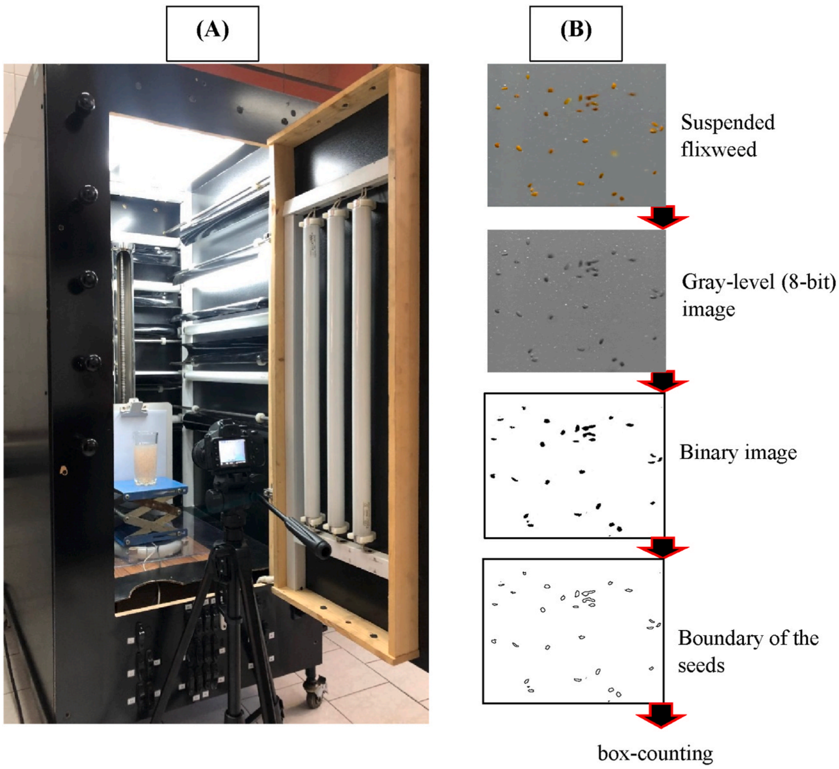

Fig. 1. Schematic presentation of Imaging process (A) and the fractal dimension determination method (B).

samples was evaluated with the Weltman model (Equation (3)):

$$\tau = A + B(\ln t) \tag{3}$$

where (t) is time of shearing (s), A represents the initial shear stress (Pa), and parameter B shows the time coefficient of structure (Pa) or the speed of food structure degradation.

2.4. Formation time of instant polymeric structured systems

By applying constant tension with a stirrer (50 rpm), the formation time of the instant structured system was measured based on two factors: not observing the solid particles in the environment and the suspension of flixweed seeds.

2.5. Stability of flixweed seeds in polymeric structured system during storage

The prepared powder sample containing flixweed seeds (8 % seeds) was poured into 200 ml of water, and after stirring under a constant condition, the distribution of seeds was studied by image processing methods after stirring (0) and 3 min of storage. In order to check the stability, the fractal dimension (FD) and the percentage of suspended seeds were measured at 0 and 3 min.

A digital camera (Nikon company, model D3200, Thailand) was used for imaging with an AF-S NIKKOR lens (18–55 mm). To ensure the most accurate results, we took great care to prepare uniform light. The pictures were captured in a dark box with black walls, and it was equipped with a fluorescent lamp, a stabilizing base and a camera. The lamps were installed at a distance of 45 cm above the sample and at an angle of 45° to prevent light reflection. A white screen was placed behind the samples, further enhancing the precision of our imaging process.

2.5.1. Fractal dimension

Different methods can be used to measure the fractal properties of an object or geometric structure. One common method to determine the fractal dimension is the box-counting method, which provides the fractal dimension of an object or image (Fig. 1(A and B)). The fractal dimension obtained from box counting indicates the level of complexity or the amount of detail across different scales [19]. In this study, 70 % of the top surface of the glass was cropped and converted to a gray-level (8-bit) image. These images were then converted into binary images, and the boundary of the seeds was extracted. Finally, the fractal dimension was calculated using the box-counting method with ImageJ software (National Institutes of Health, USA), version 1.45s.

2.5.2. Percentage of suspended seeds

To measure the percentage of suspended seeds, the number of seeds covering 70 % of the glass's top surface was measured at 0 and 3 min using image processing methods. First, the images were enhanced using a filter. Then, the color images were converted to grayscale, and the most significant rectangular cross-section covering 70 % of the top surface of the glass was captured. After adjusting the threshold, the number of seeds was calculated at 0 and 3 min using ImageJ software, and the number of suspended seeds after this time was reported as a percentage.

2.6. Suspension of flixweed seeds in the polymeric structured system

2.6.1. Determining the volume and particle density of flixweed seeds

To determine the volume of flixweed seeds, the pycnometer was first cleaned with deionized water and then dried in an oven. It was then weighed using a digital scale with an accuracy of 0.0001 g. After that, the pycnometer was filled with toluene, capped, and weighed again after removing excess fluid and drying the body. Next, the pycnometer was emptied of toluene, washed with deionized water, and dried in an oven. One hundred flixweed seeds were placed into the pycnometer, and the weighing process was repeated. Afterward, the pycnometer containing flixweed seeds was filled with toluene, capped, and weighed again after drying the body. Finally, the volume of flixweed seeds was calculated using a specific equation (Eq. (4)):

$$V_s = \frac{\left(w_{pf} - w_p\right) - \left(w_{pfs} - w_{ps}\right)}{p_f} \tag{4}$$

The total volume of the seeds was divided by the number of seeds to calculate the volume of each seed. The weight of the weighed seeds was divided by the measured total volume to calculate the particle density of the seeds.

2.6.2. Determining the surface area of flixweed seeds

The small size of flixweed seeds makes it difficult to directly measure their dimensions and surface area accurately. Therefore, we used an image processing method to measure the surface area of the seeds. We prepared images of the seeds in a controlled light environment and separated the seeds from the background or other objects. Then we used a process called thresholding to analyze the images. By calibrating the pixel scale to millimeters, we were able to calculate the surface area of the seeds.

2.6.3. Suspending the flixweed seeds in the system

The stability of particles in a fluid is examined by analyzing Flixweed seeds as spherical and assessing the forces acting on their surface. The particle's behavior in the fluid is influenced by its weight force, buoyancy force, and the force associated with the yield stress of the fluid **(F_y)**. The particle's position in the fluid is determined based on the balance of the particle weight and buoyancy force, accounting for the yield stress (Fig. 2). The particle weight force can be calculated using the density (ρg) and particle volume (Vg) with the following equation (Eq. (5)):

$$F_g = \rho_g V_g \tag{5}$$

The buoyancy force can be calculated using equation (6), which takes into account the volume of the particle (Vg) and the density of the fluid (ρm).

$$F_b = \rho_m V_g \tag{6}$$

The yield stress force is determined by the fluid yield stress (σ0) and the particle surface area (A) in a single direction, as calculated by the following equation (Eq. (7)).

$$F_{\sigma_0} = \sigma_0 A \tag{7}$$

Based on equation (8), we can assess a particle's stability in a fluid. Suppose the combined forces acting on the particle, including weight and buoyancy, are equal to or less than the force resulting from the yield stress. In that case, the particles will remain suspended in the environment.

$$F_{\sigma_0} = F_g - F_b \tag{8}$$

2.7. Sensory evaluation

The formulated samples of instant powder were assessed using the 5-point hedonic method to evaluate its acceptance, independent of its sensory properties such as aroma and taste. This assessment was conducted without flixweed seeds, and the samples were evaluated in terms of solubility, appearance, consistency and overall acceptance of the system. The 25 semi-trained panelists from the Research Institute of Food Science and Technology students were given a predetermined quantity of instant powders in sachets dissolved in 200 cc of water to prepare the final drinking sample.

In the second part of the study, where the effect of three different sweeteners was evaluated on the physical properties of the powders, the sachets of instant powders also contained flixweed seeds. The panelists were requested to assess the appearance characteristics of the beverage samples, explicitly focusing on the arrangement and distribution of the seeds within the final product. In order to remove the effect of the samples on each other, the panelists were asked to drink some water between the samples.

2.8. Statically analysis

A completely randomized with factorial design was used for the statistical analysis of the results. The data were compared by analysis of variance (ANOVA) and the difference between means using SPSS 16 software by Duncan's multiple range test (DMRT) at a significance level of 0.05. Microsoft Excel 2007 software was used to draw the curves. Data fitting was done using MATLAB 2015a software. Image processing was done with ImageJ software (version a48.1, USA).

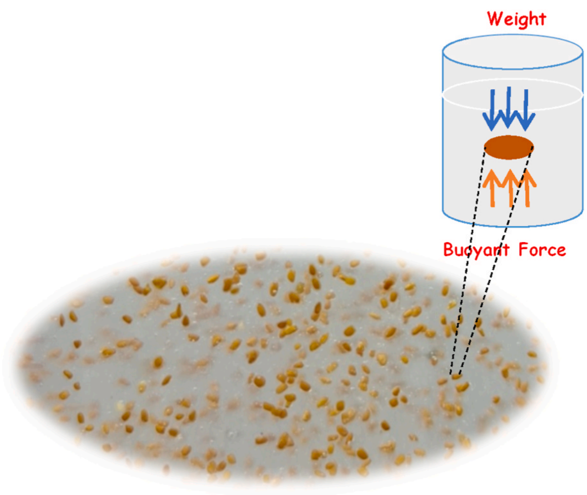

Fig. 2. Schematic presentation of the forces applied on a sinking flixweed seed in beverage.

3. Results and discussion

3.1. Rheological properties

3.1.1. Time independent rheological parameters

The rheological test data for samples without flixweed seeds were analyzed using power-law and Casson models ($R^2 > 0.98$) (Table 1). According to the Power-law model, all CMC/XG solutions exhibited shear-thinning behavior with flow behavior index (n) values lower than 1 under all conditions. The consistency coefficient values ranged from 0.08 to 0.16 $Pa.s^n$. Although all samples displayed shear thinning behavior, the highest n value was observed for dispersions containing only CMC (without xanthan) ($P > 0.05$). It has been demonstrated that fluids with high shear dependence offer a pleasant mouthfeel. XG contributes to better taste perception at high viscosity compared to solutions thickened with other polysaccharides. The higher shear thinning behavior allows concentrated solutions to be easily swallowed, resulting in a pleasant and light mouthfeel [20,21].

The consistency coefficient continuously increased with the concentration of XG in the solutions. The dispersions with the highest ratio of XG had the highest consistency coefficient value (Table 1). This behavior is attributed to intermolecular interaction or entanglement, which increases the dimensions and effective molecular weight of XG macromolecules [22]. In a similar study, watermelon juice the correlation between rheology and the addition of xanthan was investigated. They reported that xanthan-induced enlargement of particles led to higher consistency efficient [23].

Based on the Casson model in Table 1, increment of XG mass ratio from 0.00 to 0.03 caused a significant increase in the yield stress ($P < 0.05$) but had no significant effect on viscosity. It was assumed that the final concentration of stabilizers (0.2 % (w/v)) was too low to influence the rheological properties of solutions [23]. In general, yield stress causes food stability under low stress. The formation of a structured fluid system by xanthan is probably due to the presence of yield stress and high viscosity in low shear stress [24]. Yield stress prevents particles from moving due to gravity and sedimentation. The evaluation of the statistical results showed a significant effect of the CMC: XG ratio on the samples' consistency coefficient and yield stress ($P < 0.05$). The most reported rheological properties are influenced by the synergistic interaction between polysaccharides, significantly increasing the viscosity or gel/elastic structure. The rheological behavior of polysaccharides depends on the structure, molecular weight, concentration, and presence of other polymers. However, some researchers reported no significant increase in viscosity resulting from the interaction effect between XG and CMC [25]. The synergistic effect of XG and CMC may be observed only at high proportions of xanthan in the mixture when small clusters of XG gel are dispersed in CMC chains. XG affects the viscosity change more than CMC because XG has a larger molecular structure than CMC, so it has higher hydration than CMC [26].

Changes in the pH of the sample preparation environment had no significant effect on the consistency coefficient, flow behavior index, viscosity, and yield stress of the solutions ($P < 0.05$). Although slightly, the consistency coefficient (k) in an acidic environments was lower than in a neutral and alkaline environments. The viscosities of xanthan gum solutions remain unchanged from a pH of 1–13. The slight increase in the consistency coefficient at pH ≥ 9 is also due to the decrease in the ionization of anionic groups in the structure of xanthan and the formation of hydrophobic bonds. However, with a further decrease in pH < 3, a significant decrease in apparent viscosity and consistency coefficient is observed, and the reason for this is mentioned in previous studies, the separation of acetyl and pyruvate groups from the molecular structure of xanthan [27,28].

It can also get that the maximum viscosity of the CMC solution is obtained at a solution pH of 5.6–9.0 and the solutions were most stable. The viscosity decreases rapidly, as the pH value decreases below 6.0. The solution became acidified. Sodium carboxymethyl cellulose gradually changed from the salt type into the water-insoluble acid type and precipitated from the solution. Most of the salt type changes into the acid type forms a three-dimensional network structure and precipitates out, when the pH value is below 2.5. The viscosity also decreases, when the pH reaches above 9.0. This is because the association between the un-substituted hydroxyl group and the alkali molecules helps to promote cellulose dispersion. According to the selected pH range, there has been stability of CMC [29,30]. The slight decrease in the viscosity of the samples in the acidic environment can also be due to the change in the structure of the CMC polymer. Excessively large or small pH conditions affect the solution viscosity. The solution viscosity can be increased by changing the CMC-Na solution pH.

3.1.2. Time dependent rheological parameters

Regarding the time dependent rheological behavior, it was found that the CMC/XG solution have thixotropic behavior. The parameters of the Weltman model of the samples at different pH are summarized in Table 1. The failure of the cross links in the polymeric network by shear stress during time caused the thixotropic behavior of the colloidal solutions. The amount of parameter A, which represents the initial shear stress, was higher in the beverage containing only CMC than in mixed solutions containing CMC/XG. Parameter B represents the time coefficient of thixotropic degradation or the rate of degradation of food structure, with increasing amount of xanthan. This coefficient decreased in acidic environment. But in neutral and alkaline conditions, the presence of XG increased the amount of B. The increase of B indicated the regularization of the network structure.

3.2. Formation time of the polymeric structured system in beverage

In this study, the effects of pH, CMC/xanthan ratio, and their interaction on instant gel formation time were found to be significant ($p < 0.05$) (Table 2). The results indicated that as the pH increased from acidic to alkaline, the formation time of the instant structured system decreased. At pH 9.0, the CMC/xanthan mixtures formed faster than at pH 4.5 and 6.0. The rate and extent of structure forming accelerated as the pH increased, regardless of the CMC: XG mass ratios in all formulations at pH 4.5 and 6.0. Xanthan gum (XG) has a

Table 1
Time dependent/independent rheological characteristics of polymeric system at different concentrations of carboxymethyl cellulose (CMC)-xanthan gum (XG) and pH values in presence of sucrose.

pH	CMC	Xn	Time independent						Time independent		
			Power-law model			Casson model			Weltman		
			k (Pa.s^n)	n	R^2	η (Pa.s)	τ_0 (Pa)	R^2	A (Pa)	-B (Pa)	R^2
4.5	0.20	0	0.08 ± 0.02^{d}	0.73 ± 0.00^{a}	0.99	0.02 ± 0.00^{a}	0.03 ± 0.00^{d}	0.98	4.12 ± 0.02^{c}	0.09 ± 0.00^{b}	0.98
	0.19	0.01	0.12 ± 0.03^{c}	0.72 ± 0.01^{a}	0.99	0.03 ± 0.00^{a}	0.07 ± 0.00^{a}	0.98	4.01 ± 0.03^{d}	0.07 ± 0.02^{c}	0.97
	0.18	0.02	0.14 ± 0.01^{b}	0.71 ± 0.03^{a}	0.99	0.03 ± 0.00^{a}	0.07 ± 0.00^{a}	0.98	2.66 ± 0.05^{i}	0.05 ± 0.01^{c}	0.98
	0.17	0.03	0.15 ± 0.03^{a}	0.70 ± 0.01^{a}	0.99	0.03 ± 0.00^{a}	0.05 ± 0.00^{c}	0.98	3.31 ± 0.03^{g}	0.03 ± 0.01^{cd}	0.95
6	0.20	0	0.09 ± 0.02^{d}	0.73 ± 0.02^{a}	0.99	0.02 ± 0.01^{a}	0.03 ± 0.00^{d}	0.98	4.39 ± 0.01^{a}	0.04 ± 0.02^{c}	0.96
	0.19	0.01	0.13 ± 0.03^{c}	0.72 ± 0.00^{a}	0.99	0.03 ± 0.01^{a}	0.05 ± 0.00^{c}	0.98	4.33 ± 0.03^{a}	0.05 ± 0.01^{c}	0.97
	0.18	0.02	0.14 ± 0.03^{b}	0.70 ± 0.03^{a}	0.99	0.03 ± 0.00^{a}	0.06 ± 0.00^{b}	0.98	3.61 ± 0.01^{f}	0.03 ± 0.01^{cd}	0.98
	0.17	0.03	0.16 ± 0.00^{a}	0.70 ± 0.03^{a}	0.99	0.03 ± 0.00^{a}	0.07 ± 0.00^{a}	0.98	2.73 ± 0.00^{h}	0.06 ± 0.02^{c}	0.98
9	0.20	0	0.09 ± 0.02^{d}	0.73 ± 0.01^{a}	0.99	0.02 ± 0.00^{a}	0.02 ± 0.00^{d}	0.98	4.04 ± 0.00^{e}	0.06 ± 0.03^{c}	0.98
	0.19	0.01	0.12 ± 0.03^{c}	0.72 ± 0.01^{a}	0.99	0.03 ± 0.00^{a}	0.05 ± 0.00^{c}	0.98	4.28 ± 0.00^{b}	0.04 ± 0.01^{c}	0.79
	0.18	0.02	0.15 ± 0.03^{b}	0.70 ± 0.01^{a}	0.99	0.03 ± 0.00^{a}	0.07 ± 0.00^{a}	0.98	3.63 ± 0.02^{f}	0.02 ± 0.01^{d}	0.91
	0.17	0.03	0.16 ± 0.00^{a}	0.70 ± 0.00^{a}	0.99	0.03 ± 0.00^{a}	0.07 ± 0.01^{a}	0.98	2.38 ± 0.02^{j}	011 ± 0.01^{a}	0.98

The values were inserted as "mean ± standard deviation" of measurements and the different letters in column show statistically significant difference ($p < 0.05$) between samples.

Table 2
Formation time and stability of the immediate structured gel systems at different concentrations of carboxymethyl cellulose (CMC)-xanthan gum (XG) and pH values in presence of sucrose.

pH	CMC (%)	XG (%)	formation time(s)	Stability of the immediate structured gel systems during storage			
				Suspended seeds (%) after 3 min	FD*, t = 0 min	FD, t = 3 min	Difference of FD during storage
4.5	0.20	0	30.54 ± 0.02^{d}	24.82 ± 6.35^{bc}	1.09 ± 0.00^{a}	0.95 ± 0.00^{c}	0.14
	0.19	0.01	35.01 ± 0.02^{c}	25.64 ± 4.25^{bc}	1.04 ± 0.02^{a}	0.96 ± 0.09^{abc}	0.08
	0.18	0.02	38.00 ± 0.06^{b}	40.98 ± 2.17^{a}	1.02 ± 0.00^{a}	0.97 ± 0.06^{abc}	0.05
	0.17	0.03	43.03 ± 0.05^{a}	43.57 ± 6.52^{a}	1.04 ± 0.07^{a}	0.98 ± 0.06^{abc}	0.06
6	0.20	0	25.30 ± 0.09^{e}	23.20 ± 5.29^{bc}	1.07 ± 0.08^{a}	0.94 ± 0.08^{bc}	0.13
	0.19	0.01	21.12 ± 0.11^{f}	42.57 ± 5.04^{a}	1.12 ± 0.10^{a}	1.00 ± 0.03^{abc}	0.12
	0.18	0.02	21.30 ± 0.05^{f}	45.31 ± 6.15^{a}	1.23 ± 0.22^{a}	1.14 ± 0.02^{a}	0.09
	0.17	0.03	20.02 ± 0.01^{g}	49.83 ± 1.09^{a}	1.17 ± 0.26^{a}	1.12 ± 0.08^{a}	0.05
9	0.20	0	16.43 ± 0.05^{h}	11.25 ± 0.77^{d}	1.18 ± 0.18^{a}	0.90 ± 0.11^{c}	0.28
	0.19	0.01	14.00 ± 0.05^{i}	19.23 ± 1.41^{cd}	1.06 ± 0.02^{a}	0.97 ± 0.05^{abc}	0.09
	0.18	0.02	14.43 ± 0.09^{i}	24.36 ± 2.05^{bc}	1.03 ± 0.08^{a}	0.98 ± 0.03^{abc}	0.05
	0.17	0.03	12.21 ± 1.03^{j}	31.32 ± 2.55^{b}	1.08 ± 0.10^{a}	1.01 ± 0.03^{abc}	0.07

The values were inserted as "mean ± standard deviation" of measurements and the different letters in column show statistically significant difference ($p < 0.05$) between samples.
FD: Fractal dimension.

pKa of 4.65, meaning it is influenced by pH and can change its structure at low pH values [31]. Xanthan gum molecules may undergo order-disorder structural changes due to varying ionic strength. They can either exhibit an ordered helical conformation involving hydrogen bonds between the side chains and the backbone, or they can form a disordered helix (broken helix) [28]. Similarly, CMC is an anionic polyelectrolyte that becomes protonated and insoluble at low pH values. Considering the dissociation constant of carboxylic groups in CMC (pKa = 3.3 in a salt-free solution, the effect of pH was only observed for the acidic buffer [32].

While XG concentrations have been observed to increase formation time (Table 2), the slow dissolution time of XG is a known limitation. However, this can be addressed by adjusting physical conditions such as temperature, concentration, stirring, and the presence of other polymers [33]. This practical approach can significantly improve XG dispersion. Additionally, increasing the CMC ratio in di-polymeric interpenetrating gel networks has been found to enhance mechanical strength and adjustability, making them a promising instant structured material (Table 2).

3.3. Stability of polymeric structured systems

The percentage of suspended seeds and difference of fractal dimension was applied for describe the stability of suspension system. The concept of fractal has been employed to describe the complicated structure of polymer gel [34]. The fractal dimension results were consistent with the stability of suspended seeds, which refers to the stability of seeds suspended in a gel system. The FD difference of polymeric structured systems between storage time (0–3 min) showed the changes in the distribution of seed in the structured system. Lower difference showed higher stability on the system.

The highest (%) suspended seeds (49.83 ± 1.09 %) and lowest difference of FD values (1.12 ± 0.08) after 3 min were observed in samples containing 0.17 % CMC and 0.03 % XG (Table 2). Increasing the XG mass ratio increased the stability of suspended seeds. The lowest and highest amounts of suspended seeds were 11.25 ± 0.77 % and 49.83 ± 1.09, related to samples without XG and 0.17CMC-0.03XG, respectively. The presence of XG increased the stability of the suspension system by strengthening the network and increasing the viscosity. Polymeric structured systems with more XG ratios showed a lower difference of FD, because of stronger hydrogen bond network with gelation. The lowest stability was obtained in samples without xanthan. The presence of xanthan increased the stability of the suspension system by strengthening the network and increasing the viscosity. In supramolecular gels with amphiphilic

Table 3
Density and yield stress of the beverage solution and the result of the forces acting on the flixweed seeds in the beverage environment at different concentrations of carboxymethyl cellulose (CMC)-xanthan gum (XG) and pH values in presence of sucrose.

PH	CMC (%)	Xanthan (%)	Density	The result of the forces acting on the seed (Fg-Fb)(Pa)	Yield stress (Pa)
4.5	0.20	0.00	1.106	0.0000672	0.00052
4.5	0.19	0.01	1.104	0.0000668	0.001368
4.5	0.18	0.02	1.105	0.0000670	0.001213
4.5	0.17	0.03	1.104	0.0000668	0.000867
6	0.20	0.00	1.104	0.0000668	0.00052
6	0.19	0.01	1.104	0.0000668	0.000867
6	0.18	0.02	1.104	0.0000668	0.00104
6	0.17	0.03	1.104	0.0000668	0.001213
9	0.20	0.00	1.104	0.0000668	0.000347
9	0.19	0.01	1.104	0.0000668	0.000867
9	0.18	0.02	1.104	0.0000668	0.001213
9	0.17	0.03	1.104	0.0000668	0.001213

molecules, their cross-linking prevents reduction of FD during storage [35]. These observations strongly suggest that formation network structure drives reduction of FD during storage which confirmed by rheological studies (Table .1). CMC: XG gels are out-of-equilibrium soft solids composed of attractive Brownian particles that form a space-spanning network at low volume fractions. The elastic properties of these systems result from the network microstructure, which remains physically stable for long periods of time [36].

By changing the pH, the stability of the suspended seeds was affected. Suspended seed reached its maximum amount at natural conditions (49.83 %). The lowest stability was observed in the alkaline environment (11.25 %), which is related to the weakening of the network and the lower viscosity of the polymers in this environment (Table 1). When hydrocolloids cover the surface of each of the suspended particles, the particles lose their normal surface properties and assume the surface properties of the protective colloid. The protective colloid has an affinity for the continuous phase, connecting the two phases and stabilizing the suspension [37].

3.4. Stability of the polymeric structured system for suspension

To suspend particles in a fluid, the total forces (result of buoyancy force and weight force) acting on the particle should be smaller than the restraining force (yield stress): F_g-F_b < Fy. The particle's average weight, density, and volume were calculated as 0.000152 g, 0.71904 g/ml, and 0.000215 ml, respectively. The fluids' density values in Table 3 showed no difference among the examined beverages. Examination of the total forces acting on the seeds (F_b-F_g) in different environments showed positive values, indicating that the flixweed seeds settled in the fluid, but the yield stress (F_y) of the structured system was higher than these values, proving that the seeds remained suspended in the environment. The yield stress **(F_y)** values obtained from the fitted Casson model on data in all environments were more significant than the forces acting (F_b-F_g) on the seed (Table 3). Therefore, the seed became well suspended in the designed environments. This weight stability caused the stabilization of the samples' density due to the direct relationship between mass and density [38].

3.5. Sensory properties

The type and concentration of biopolymer did not have a statistically significant effect on the sensory characteristics of the beverage. However, the results of the sensory evaluation indicated that panelists preferred beverages prepared with 0.17CMC-0.03XG (refer to Table 4). Xanthan gum was used in the beverage as a thickening and stabilizing agent, improving the appearance, texture, and mouthfeel of the product. It also enhances taste, solubility, and compatibility with other components. Additionally, in reconstituted beverages, xanthan gum acts as a taste enhancer and improves viscosity. When added during beverage processing, xanthan gum acts as a thickening and suspending agent, contributing to a desirable product appearance, texture, and mouthfeel, as well as enhancing taste and rapid viscosity development.

3.6. Effect of sweetener on physical characteristics of beverage

3.6.1. Time independent rheological properties

The impact of stevia, xylitol, and sucrose on the viscosity of CMC-XG solutions is summarized in Table 5. The results indicate that the viscosity decreased significantly ($P < 0.05$) with increased stevia sweetener content. According to power-law and Casson models, the coefficient of consistency (0.06 ± 0.00 Pa s) and yield stress (0.03 ± 0.00 Pa s) of the sample containing stevia were lower than those of the sample containing sucrose, which were equal to 0.16 ± 0.00 Pa s and 0.07 ± 0.00 Pa s, respectively However, no significant change was observed in the sample's viscosity (Table 5). However, no significant change was observed in the sample's viscosity. According to Saniah and Samsiah (2012), increasing the amount of stevia and reducing sucrose decreased the viscosity of carbonated beverage samples. These researchers also pointed out that sugar in beverages contributes to mouthfeel and texture. Therefore, when using stevia as a sweetener in beverages, pair it with a thickening agent like carboxymethyl cellulose and pectin to maintain viscosity and concentration at appropriate levels to ensure consumer satisfaction [39]. The type of sweetener affects the viscosity of beverages. Disaccharide sugars such as sucrose increase viscosity in the medium due to their hydrophilic properties. Additionally, molecular size is a factor in forming hydrogen bonds with water, and sucrose's low molecular weight and high water absorption tendency contribute to increased viscosity [40]. Xylitol exhibited a similar viscosity to sucrose.

The higher values of (k) parameter were noticed when xylitol and sucrose were added. This means that solutions with stevia had a

Table 4
Effect of biopolymer systems on sensory characteristics of suspended flixwees seed beverage at different concentrations of carboxymethyl cellulose (CMC)-xanthan gum (XG) and pH = 6 in presence of sucrose.

CMC:XG mass ratio (%)	Solubility acceptance	Appearance	Consistency	Overall acceptance
0.2:00	2.6 ± 0.82^a	3.20 ± 1.30^a	3.40 ± 1.05^a	3.27 ± 0.96^a
0.19:0.01	3.13 ± 0.74^a	3.47 ± 0.86^a	3.87 ± 0.74^a	3.27 ± 0.88^a
0.18–0.02	3.27 ± 0.80^a	3.53 ± 0.64^a	4.00 ± 0.65^a	3.60 ± 0.63^a
0.17:0.03	3.40 ± 1.18^a	3.87 ± 0.74^a	4.13 ± 0.74^a	4.00 ± 0.74^a

The values were inserted as "mean ± standard deviation" of measurements and the different letters in column show statistically significant difference (*p < 0.05*) between samples.

Table 5
The effect of different sweeteners on time independent/dependent rheological properties of the instant polymers suspension system (pH = 6; 0.17% CMC-0.03%XG).

Sweetener	time independent						time dependent		
	Power-law			Casson			Weltman		
	k (Pa.s^n)	n	R^2	η (Pa.s)	τ_0(Pa)	R^2	A (Pa)	-B (Pa)	R2
Stevia	0.06 ± 0.00^b	0.78 ± 0.00^a	0.99	0.02 ± 0.00^a	0.03 ± 0.00^b	0.98	2.32 ± 0.03^b	0.02 ± 0.00^b	0.94
Xylitol	0.14 ± 0.02^a	0.72 ± 0.01^b	0.99	0.03 ± 0.00^a	0.06 ± 0.00^a	0.98	3.79 ± 0.03^a	0.05 ± 0.00^a	0.99
Sucrose	0.16 ± 0.00^a	0.70 ± 0.03^b	0.99	0.03 ± 0.00^a	0.07 ± 0.00^a	0.98	2.73 ± 0.00^c	0.06 ± 0.03^a	0.98

The values were inserted as "mean ± standard deviation" of measurements and the different letters in column show statistically significant difference ($p < 0.05$) between samples.

lower consistency, while there were no significant differences between the values of the solutions with sucrose and xylitol. The Casson viscosity (η) of the solution with stevia was the lowest, confirming that xylitol and sucrose are better at increasing the apparent viscosity of the xanthan-CMC blend dispersion. This result is likely due to a network forming between the carboxyl groups of the gums and sucrose [41,42]. Bak and Yoo (2023) also provided a similar explanation for the change in the gum structures in the presence of sucrose, either through competition between gums and sugar for holding water or through sucrose-gum interactions [43].

3.6.2. *Time dependent rheological properties*

The results showed that the amount of parameter A of the Weltman model (initial shear stress) in the sample containing xylitol was significantly higher than in the samples containing sucrose and stevia. Also, parameter B (degradation speed) of samples containing sucrose sweetener was higher (Table 5). It has been reported that due to hygroscopicity and water trapping effects, the hydrocolloid requirement for structural stabilization is affected by sugar content. More hydrocolloid is required when using sucrose substitute sweeteners such as stevia [1].

3.6.3. *Formation time of instant structured system*

As shown in Table 6, the observations showed a rise in the formation time with adding sucrose in constant stirring. This is because several crosslinks between XG and sucrose are hydrophilic, thereby enhancing the network structure formation times. Notably, the gel formation time decreased remarkably when xylitol and stevia content were added. Similar results were reported by Akesowan (2015), which demonstrated that xylitol affects remaining or holding unbound or free water molecules in the presence of xanthan and κ-carrageenan gel solution [44].

3.6.4. *Stability of polymeric structured systems*

The study investigated how different sweeteners affect the stability of gel systems. The results showed that the sample containing sucrose had the highest stability, as anticipated based on its rheological behavior (Table 6). Xylitol, on the other hand, led to lower stability. The minor difference in the FD also supported the excellent stability of the system in the presence of sucrose.

3.6.5. *Stability of the structured system for suspension*

The density of fluids with different sweeteners (Table 6) showed no significant difference between the density numbers of the beverage environments in the presence of different sweeteners. Brind's examination of the forces acting on the grain (F_b-F_g) and the amount of yield stress showed that because the yield stress (F_y) of the structured system is higher than these values, the grains are

Table 6
Effect of different sweeteners on the suspension of seeds in the optimal environment (0.17CMC-0.03XG; pH = 6) (formation time, stability, and sensory properties).

	sweetener type/Suspending properties	Stevia	Xylitol	Sucrose
	formation time (s)	15.05 ± 0.02^b	14.75 ± 0.03^b	20.02 ± 0.01^a
Stability of Suspended seeds during storage	Suspended seeds (%) after 3 min	28.34 ± 1.15^b	21.41 ± 1.62^c	49.83 ± 1.09^a
	FD, t = 0 min	1.39 ± 0.04^a	1.13 ± 0.11^a	1.17 ± 0.26^a
	FD, t = 3 min	1.10 ± 0.11^a	0.83 ± 0.03^b	1.12 ± 0.08^a
	Difference of FD during storage	0.29^a	0.30^a	0.05^b
	Density	1.082	1.105	1.105
	The result of the forces acting on the seed (Fb-Fg)(Pa)	0.0000624	0.0000670	0.0000669
	Yield stress (Pa)	0.00052	0.00104	0.00121
Sensory properties	Solubility acceptance	3.93 ± 0.70^a	3.53 ± 0.83^a	3.40 ± 1.18^a
	Appearance	4.27 ± 0.80^a	3.47 ± 1.12^a	3.87 ± 0.74^a
	Consistency	4.13 ± 0.64^a	3.87 ± 0.99^a	4.13 ± 0.74^a
	Overall acceptance	3.93 ± 0.59^a	3.47 ± 0.91^a	4.00 ± 0.75^a

The values were inserted as "mean ± standard deviation" of measurements and the different letters in column show statistically significant difference ($p < 0.05$) between samples.
FD: Fractal dimension.

suspended in the environment. As the results presented in Table 6 show, the highest yield stress is related to the selected solution, i.e., the sucrose solution.

3.6.6. *Sensory properties*

In Table 6, the impact of different sweeteners on the sensory characteristics of a beverage is presented. The mean values of the sensory attributes for beverages made with stevia, sucrose, and xylitol were similar. However, the appearance score, which indicates the uniform distribution of the seeds in the beverage and the clarity of the liquid, was highest for the beverage containing stevia. Using a small amount of stevia as the sweetener produced a clear beverage consumers received well. The overall acceptance scores indicated that, after sucrose, stevia was the most preferred sweetener based on sensory perception.

4. Conclusion

The results of this research showed that the use of a mixture of carboxymethyl cellulose and xanthan (in different ratios (0:0–17:0:0; at a fixed weight of 2 %) improved the ability to suspend flixweed seeds in acidic, neutral, and alkaline environments. The samples in different proportions of biopolymers and pH conditions had thixotropic behavior, indicating the connection of polymer chains and creating a three-dimensional structure. However, increasing the percentage of xanthan in the polymer mixture system increased the system's stability as the system yield stress values increased, which led to better suspension of the seeds. The best system for suspending was 0.17 carboxymethyl cellulose: 0.03, which had the highest overall acceptance, yield stress, and percentage of suspended seeds over time. pH values also significantly affected stabilization ability and speed of structured system formation. The most stable system was observed in a neutral environment. The impact of pH, carboxymethyl cellulose/xanthan ratio, and their interaction on the speed of structured system formation was significant ($P < 0.05$). Regarding sensory evaluation, the neutral environment scored the highest acceptance and attractiveness. The type of sweetener changed the structural and rheological properties of the structured system by influencing the water absorption capacity. The consistency coefficient and yield stress were significantly reduced in the presence of stevia. The highest stability was found in the sample containing sucrose, which was expected due to the rheological behavior of the solutions, and the lowest stability was related to xylitol. The sensory evaluation of the samples showed that sucrose was the most acceptable sweetener by the panelist. The present investigation concluded that the flixweed seeds powder system containing 0.17%CMC and 0.03 % XG showed significantly better viscosity, suspension ability, and storage stability than other mixtures.

CRediT authorship contribution statement

Sara Naji-Tabasi: Writing – review & editing, Supervision, Project administration, Investigation, Formal analysis, Conceptualization. **Bahareh Emadzadeh:** Writing – original draft, Supervision, Project administration, Investigation, Conceptualization. **Seyedeh Fatemeh Mousavi:** Writing – original draft, Investigation, Formal analysis. **Saeedeh Shahbazizadeh:** Writing – original draft, Validation, Formal analysis. **Zahra Damavandi:** Writing – review & editing, Validation, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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