Development of low-fat mayonnaise containing polysaccharide gums as functional ingredients

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Abstract

BACKGROUND: The objective of this study was to develop a low-fat (LF) mayonnaise containing polysaccharide gums as functional ingredients. Xanthan gum (XG, 15 g kg⁻¹), citrus fiber (CF, 100 g kg⁻¹) and variable concentration of guar gum (GG) were used to formulate the optimum ratios of polysaccharide gums as fat replacers. The fat content in LF mayonnaise was reduced to 50% if compared with full-fat (FF) mayonnaise, and the products still maintained ideal rheological properties.

RESULTS: The rheological parameters showed that there were no ($P > 0.05$) differences in yield stress, viscosity and flow behavior index between XG + 10 g kg⁻¹ GG, CF + 5 g kg⁻¹ GG and FF control. LF mayonnaises had lower caloric values and higher dietary fiber content than the FF counterpart. Scanning electron microscopy (SEM) micrographs illustrated that the network of aggregated droplets in LF treatments contained a large number of interspaced voids of varying dimensions. Furthermore, in a comparison of sensory evaluation of LF treatments with commercial and our FF mayonnaises, there were no ($P > 0.05$) differences in any sensory scores among XG + 10 g kg⁻¹ GG control.

CONCLUSION: This study shows that XG + 10 g kg⁻¹ GG and CF + 5 g kg⁻¹ GG could be used in LF mayonnaise formulations based on its multiple functions on processing properties.

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Keywords: low-fat mayonnaise; polysaccharide gums; xanthan gum; guar gum; citrus fiber; rheological properties

INTRODUCTION

Mayonnaise is a common food product worldwide. It is traditionally prepared by using egg yolk or the whole egg to emulsify a large amount of oil. The oil content of traditional mayonnaise is more than 65%;¹ hence it is generally regarded as a high-fat and high-caloric food. At the same time, a positive relationship between dietary fat and development of cardiovascular diseases, hypertension and obesity was reported previously, thus decreasing consumption of low-fat or low-energy products.² Hence a development of low-fat (LF) mayonnaise is an important issue not only for the food industry but also for consumers. As a component of mayonnaise, fat contributes to the flavor, appearance, texture, and shelf-life. When developing LF mayonnaise, it is difficult to imitate the qualities of traditional mayonnaise. Generally, nonfat ingredients such as gums, starches, and proteins with different functionalities are incorporated into fat-reduced products. Many of these result in loss of quality and attributes in LF products compared to full-fat (FF) products.³

It is expected that a new fat replacer will not only improve processing functionalities but also contribute to nutritional benefits. For example, polysaccharide gels containing considerable dietary fiber are good substitutes for fat.^{4,5} Polysaccharide gels, including pectin, guar gum (GG) and xanthan gums (XG), have been increasingly studied as fat replacers in food processing, e.g. in LF meat products. However, few reports focus on reduced-fat mayonnaise.^{6,7} Rheological properties quantitatively contribute to texture characteristics; hence they are often applied to study

the influence of texture in different formulations of mayonnaise.^{8,9} XG is one of the polysaccharide gums often used in mayonnaise alone, or together with other gums in salad dressings, to produce the desired rheological properties.^{5,10} In addition, citrus fiber (CF) is used as a fat replacer, stabilizer and emulsifier in ice cream processing, but does not affect the viscosity, overrun or sensory properties of ice cream.¹¹

There are no reports related to the application of natural dietary fibers as fat replacers in LF mayonnaise, nor a complete investigation of its rheological and texture properties. Therefore, this study investigated the effects of XG and CF in combination with GG as fat replacers in different mayonnaise formulations by detecting their physicochemical, rheological and sensory properties.

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Table 1. Formulations of full-fat and low-fat mayonnaises

	Full fat mayonnaise (g kg ⁻¹)	Low-fat mayonnaise (g kg ⁻¹)
Egg yolk	140.5	140.5
Soybean oil	730	365
polysaccharide gums	0	365
Vinegar	92	92
Sugar	27	27
Salt	10.8	10.8

MATERIALS AND METHODS

Materials

XG and CF were purchased from Dah Chung Trading Co., Taiwan. GG was provided by Gemfont Co., Taiwan. Other ingredients for the experimental mayonnaises, such as egg, apple vinegar, salt, sugar and soybean oil, were purchased from a local supermarket. All chemicals were of analytical grade (extra pure).

Preparation of the fat replacers

There were three kinds of polysaccharide gum used as fat replacers in this study. First, XG and CF were dissolved in deionized water, which was adjusted to concentrations of 15 and 100 g kg⁻¹, respectively. The XG–GG mixture was formed by mixing the XG gel (15 g kg⁻¹) with 0, 5.0, 7.5, 10.0 or 12.5 g kg⁻¹ GG. The CF–GG mixture was prepared by mixing the CF gel (100 g kg⁻¹) with 0, 2.5, 5.0 or 7.5 g kg⁻¹ GG.

Preparation of the mayonnaise

The recipes and preparation method of the mayonnaise were modified from the procedures of Ma *et al.*¹² The recipes of the FF mayonnaise as control and the LF counterpart are shown in Table 1. First, egg yolk and apple vinegar were mixed in a plastic beaker and blended using a mixer (HD-0025, Yeong Jyi Co., Taiwan) at $4 \times g$ for 10 s. Other ingredients (including fat replacers) except oil were then added and stirred at $38 \times g$ for 1 min. Finally, the soybean oil was added slowly (flow rate 200 mL min⁻¹), and all the ingredients were stirred at $151 \times g$ for 2 min. Mayonnaises were transferred to a plastic sealed jar and stored at room temperature (about 25–30 °C) until further analyses.

Composition analysis

Moisture, protein, and ash contents were determined according to AOAC¹³ official methods. Fat content was determined by Marshall's method.¹⁴ Carbohydrates were determined by subtracting the sum of percentages of moisture, protein, fat, and ash from 100%. Dietary fiber was determined using the Warrand method.⁷

pH, water activity (A_w) and brightness measurements

pH and A_w values were measured at a temperature of 25 °C using a pH meter (DinSlaken) and an Aqualab water activity meter (Decagon Devices, Pullman, WA, USA), respectively. Brightness measurements (Hunter L) were analyzed using an ND-300A chromameter (Nippon Denshoku, Tokyo, Japan). The instrument was standardized before each measurement with white ceramic plates.

Optical microscope observation

The glass microscope slide was coated with a mayonnaise sample and placed on the stage of an optical microscope (Olympus cx-41, Tokyo, Japan) to obtain photomicrographs.

Scanning electron microscopy (SEM)

The sample preparation was according to the procedure of Egeland *et al.*¹⁵ Samples were coated with gold before obtaining the micrographs. Microscopy utilized a JSM-6300 scanning electron microscope (JEOL, Tokyo, Japan) at 15 kV and a magnification of 3500 $\times$.

Particle size measurement

A Mastersizer 2000 (Malvern Instruments Ltd, Malvern, UK) was used to determine the particle size distribution. Samples were diluted with 1 g kg⁻¹ sodium dodecyl sulfate (SDS). The relative index of sample to corn oil was set at 1.460 and the absorption was set at 0.00. The mean particle size was recorded as the $D(4,3)$ diameter.¹⁶

Rheology analysis

The rheological measurements were performed in a rheometer (AR-2000ex, TA Instruments, Crawley, UK). The mayonnaise flow properties at 25 °C were analyzed using a parallel stainless steel plate with a diameter of 40 mm.⁹ A thixotropic loop measurement was carried out by first increasing the shear rate logarithmically from 0 to 150 s⁻¹ for 4 min, then maintaining it at 150 s⁻¹ for 4 min, and finally decreasing it logarithmically back to 0 s⁻¹ for 2 min. The shear stress, viscosity, flow behavior index and thixotropy data were obtained by using the Herschel–Bulkley equation model as follows:

$$\tau = \tau_y + K \times \dot{\gamma}^n$$

where τ is the shear stress (Pa), τ_y is the yield stress (Pa), $\dot{\gamma}^n$ is the shear rate (s⁻¹), K is the consistency index (Pa s ^{n}) and n is the flow index.

Sensory analysis

Sensory evaluation was conducted on the samples after one-day storage at room temperature. Sensory analyses, i.e. appearance, aroma, taste, greasiness and overall acceptability, were carried out by 30 trained panelists. A nine-point hedonic scale was used with 1 = dislike extremely, 9 = like extremely. The sample presentation order was randomized.¹⁷

Statistical analysis

All experiments were replicated three times. Data were subjected to analysis of variance (ANOVA). Comparison of means used Duncan's multiple range test. Differences of $P < 0.05$ were considered to be significant. All analyses were performed using SAS (1985) for Windows.

RESULTS AND DISCUSSION

A preliminary experiment measuring rheological properties of LF mayonnaise indicated that a single polysaccharide gum, i.e. XG or CF, offered good emulsification (data not shown), but neither XG nor CF significantly achieved the rheological properties of the control mayonnaise (FF). Therefore, we evaluated other ingredients to improve flow properties of LF mayonnaise.

Figure 1. Micrographs by optical microscope of low-fat mayonnaise with different polysaccharide gums: (a) control (FF); (b) XG; (c) XG + 5 g kg⁻¹ GG; (d) XG + 7.5 g kg⁻¹ GG; (e) XG + 10 g kg⁻¹ GG; (f) XG + 12.5 g kg⁻¹ GG; (g) CF; (h) CF + 2.5 g kg⁻¹ GG; (i) CF + 5 g kg⁻¹ GG; (j) CF + 7.5 g kg⁻¹ GG.

Mayonnaise is an emulsification product with low pH. GG is a neutral gum and does not affect the pH of food products. In addition, aqueous viscosity can be increased in mixtures of GG and XG.^{5,18} The effects of different concentrations of GG with either XG or CF on quality characteristics were evaluated in this study.

Optical microscope observation

Figure 1 showed micrographs by optical microscope of LF mayonnaise with different polysaccharide gums. It showed that the oil droplets size of the XG + GG groups were nearly between 3–25 µm and apparently larger than the FF control (Fig. 1(a)–(f)). However, the oil droplets were in a close order and sizes of the CF + GG groups were similar to the FF control (Fig. 1(a), (g)–(j)), between 3 and 13 µm. The addition of GG did not change the oil droplet size and dispersion in any LF group. It was reported that GG could change the flow equation parameters in LF groups but could not influence the oil droplets sizes.¹⁹ Probably, no changes in the dispersal situation of LF mayonnaises by adding GG was due to formation of three-dimensional networks between XG and GG, or CF and GG. Liu *et al.*⁹ found that oil droplets were more rare in LF mayonnaise with low-methoxy pectin as fat replacer than in control mayonnaise. Weak-gel additives poorly disperse in solution, thus inducing a large particle size. The XG exhibits weak gel characteristics,²⁰ so that all XG + GG groups had larger, less dispersed oil droplets (Fig. 1(b)–(f)).

Rheological characteristics

The sample flow curves are presented in Fig. 2. All mayonnaise samples exhibited shear thinning and thixotropic behaviors over the whole range of shear rate studied (0–150 s⁻¹), where segments of the down curves represent values of shear stress lower than those of the up curves at the same point of each shear rate. Data also showed that the higher the shear stress, the higher the GG concentration, and that the increase in rate of shear stress gradually slowed as shearing speed increased.

Figure 2. Flow curves for low-fat mayonnaise with (a) 15 g kg⁻¹ xanthan gum; +, XG; □, XG + 5 g kg⁻¹ GG; △, XG + 7.5 g kg⁻¹ GG; ○, XG + 10 g kg⁻¹ GG; *, XG + 12.5 g kg⁻¹ GG; ■, control (FF); (b) 100 g kg⁻¹ citrus fiber and various concentrations of guar gum; +, CF; □, CF + 2.5 g kg⁻¹ GG; *, CF + 5 g kg⁻¹ GG; ○, CF + 7.5 g kg⁻¹ GG; ■, control (FF).

To identify the flow characteristics of the mayonnaise samples, the flow curves were fitted to the Herschel–Bulkley equation, as summarized in Table 2. The results represented that the yield stress (τ_y) of mayonnaise with XG or CF individually was increased markedly by adding GG. However, τ_y was reduced in mayonnaise

Table 2. Flow parameter values of low-fat mayonnaise with different polysaccharide gums

Sample	τ_y	K	n	Thixotropy
Control (FF) ^a	43.64 ± 5.31c	49.37 ± 7.20cd	0.33 ± 0.03cde	6446 ± 582.1a
XG	38.28 ± 5.56c	8.03 ± 1.66h	0.42 ± 0.05a	3289 ± 27.1c
XG + 5 g kg ⁻¹ GG	53.35 ± 5.37ab	12.53 ± 1.00h	0.36 ± 0.01b	2854 ± 352.8c
XG + 7.5 g kg ⁻¹ GG	58.19 ± 0.77a	21.29 ± 2.32g	0.31 ± 0.02de	3086 ± 170.7c
XG + 10 g kg ⁻¹ GG	44.70 ± 5.62c	45.85 ± 3.22d	0.20 ± 0.02f	2893 ± 271.2c
XG + 12.5 g kg ⁻¹ GG	47.02 ± 3.79bc	63.80 ± 3.55b	0.16 ± 0.01f	3165 ± 433.8c
CF	24.96 ± 5.76d	29.63 ± 6.78f	0.35 ± 0.04bcd	6311 ± 2020.9a
CF + 2.5 g kg ⁻¹ GG	43.33 ± 0.95c	37.40 ± 5.43e	0.38 ± 0.02ab	7321 ± 349.5a
CF + 5 g kg ⁻¹ GG	42.75 ± 5.91c	54.25 ± 0.78c	0.32 ± 0.01cde	7567 ± 781.7a
CF + 7.5 g kg ⁻¹ GG	41.56 ± 1.57c	76.43 ± 2.91a	0.28 ± 0.01e	4621 ± 360.4b

Average of mean values ± standard deviation mean values.

Means in a column followed by different letters are significantly different ($P < 0.05$).^a The mean control was full-fat mayonnaise.**Table 3.** Chemical composition analysis (g kg⁻¹) and caloric values of low-fat mayonnaise with different polysaccharide gums at optimum ratios

Samples	Moisture content	Fat	Carbohydrate	Protein	Ash	Dietary fiber ^b		Caloric values ^a
						Soluble	Insoluble	
Control ^c	165.6 ± 1.8c	765.9 ± 2.5a	35.2 ± 1.3c	22.1 ± 0.6a	11.7 ± 0.5a			7118.4 ± 20.6a
XG + 10 g kg ⁻¹ GG	523.0 ± 1.1a	399.2 ± 6.5b	43.9 ± 4.5b	21.4 ± 0.6a	12.5 ± 0.8a	6.8		3853.9 ± 39.6c
CF + 5 g kg ⁻¹ GG	493.7 ± 1.6b	401.9 ± 3.2b	69.7 ± 3.0a	22.3 ± 1.7a	12.4 ± 0.7a	15.0	13.7	3984.8 ± 20.7b

Average of mean values ± standard deviation mean values.

Means in the same test parameter followed by different letters are significantly different ($P < 0.05$).^a Caloric values = (9 × fat) + (4 × protein) + (4 × carbohydrate).^b Dietary fiber was calculated from raw material values.^c The control was full-fat mayonnaise.

with XG when the amount of GG exceeded 7.5 g kg⁻¹. The consistency coefficient (K) values were also markedly increased by addition of 7.5, 10.0 or 12.5 g kg⁻¹. These findings are in agreement with the results of Chen,²⁰ who indicated that GG increases the aqueous viscosity in a XG mixture. On the contrary, flow behavior index (n) values decreased as the concentration of GG increased. An increased level of thixotropy corresponds to a progressive breakdown of the products' structure as the time of shear is increased.²¹ Our data demonstrated that thixotropy was not affected by adding GG, but it was lower ($P < 0.05$) than in the FF control. Liu *et al.*⁹ used the combination of whey protein isolate and pectin as fat replacers in LF mayonnaise. They reported that thixotropy was greater in FF mayonnaise compared to the LF counterparts. Our results were similar.

In CF + GG groups, similarities to XG + GG groups were observed ($P > 0.05$). The K values increased as the concentration of GG increased, but n was decreased at the highest GG concentration. There were no significant differences for flow parameters between treatments with CF + 5 g kg⁻¹ GG and FF control, while n values were similar to those of XG + GG groups. According to the results of appearance (data not shown), oil droplet size and rheological characteristics (Fig. 1 and Table 2), the XG + 10 g kg⁻¹ GG and the CF + 5 g kg⁻¹ GG were chosen to be the best formulations of LF mayonnaise for further analyses.

Chemical composition and caloric values

The composition analysis and caloric values of control (FF) and LF mayonnaise containing different polysaccharide gums at optimum

ratios are listed in Table 3. Due to high moisture content of fat replacers in the preparation, the moisture content increased with addition of fat replacers, which is a typical characteristic of carbohydrate-based fat replacers.²² There were no significant differences between the LF (XG + 10 g kg⁻¹ GG and CF + 5 g kg⁻¹ GG) and control group in ash and protein concentrations. The caloric values of the LF samples were significantly ($P < 0.05$) reduced, because water is a main component of fat replacers, and XG, GG and CF are non-caloric because they are not digested or absorbed in the human digestive tract.

In this study, we used polysaccharide gums which contain a high level of dietary fiber as fat replacers. Hence dietary fiber contents of the XG + 10 g kg⁻¹ GG and the CF + 5 g kg⁻¹ GG were 6.8 g kg⁻¹ and 28.7 g kg⁻¹, respectively. According to the Food and Drug Administration's food labeling law, foods with 2.5–4.9 g of fiber per serving can be labeled as 'a good source of fiber'. The LF mayonnaise containing CF + 5 g kg⁻¹ GG meets this criterion. The LF mayonnaise with XG + GG had good texture and a light appearance, whereas the LF mayonnaise with CF + GG was rough textured, which might result from the higher dietary fiber content.

Physicochemical analyses and microstructure

The brightness (L value), A_w and pH values of the control and LF mayonnaises with different polysaccharide gums at optimum ratios after storage for one day at room temperature are shown in Table 4. The brightness of mayonnaise has a major impact on the perceived appearance of the product.¹⁷ The L values of LF-treated

Table 4. Physicochemical properties of low-fat mayonnaise with different polysaccharide gums at optimum ratios

Samples	Brightness (L)	pH	Water activity (A_w)
Control (FF) ^a	75.53 ± 0.36c	3.96 ± 0.01b	0.945 ± 0.003b
XG + 10 g kg ⁻¹ GG	80.17 ± 0.17a	3.99 ± 0.02a	0.984 ± 0.003a
CF + 5 g kg ⁻¹ GG	77.50 ± 0.35b	3.82 ± 0.05c	0.982 ± 0.001a

Average of mean values ± standard deviation mean values.
Means in the same test parameter followed by different letters are significantly different ($P < 0.05$).
^a The control was full-fat mayonnaise.

mayonnaises were significantly higher than that of FF control. Chantrapornchai *et al.*²³ reported that the emulsion changed from a grey color to an increasingly bright white color as the droplet size decreased due to an increase in light scattering. Hence the higher L values could be related to larger lipid droplets observed in LF mayonnaises with XG + GG and CF + GG (Fig. 1 and Table 4).

The A_w of LF mayonnaises increased, as expected, with increased percentage of fat replacers mainly due to the increased of water-holding capacity of the formulations. Chirife *et al.*²⁴ reported that the A_w of FF mayonnaises (77–79% oil) was about 0.93 and that of LF samples (37–41% oil) was higher, i.e. close to 0.95.

According to Hatchcox *et al.*,²⁵ the pH of the fat replacer formulations would be higher than that of the FF formulations due to the dilution of acetic acid in the aqueous phase of the LF formulations. However, the XG + 10 g kg⁻¹ GG group had a pH equal to the control (FF) and the CF + 5 g kg⁻¹ GG had a lower pH than the control (FF). This could be explained by acetic acid residue remaining in the CF preparation after acid extraction.

A comparison of the structures in various mayonnaises by SEM is shown in Fig. 3. The control (FF) and CF + 5 g kg⁻¹ GG (Fig. 3(a), (c)) mayonnaises had a small and relatively uniform droplet distribution (monodisperse) compared to the XG + 10 g kg⁻¹ GG group. Gutierrez *et al.*²⁶ illustrated that the viscosity of polydisperse emulsions was significantly lower than that observed in equivalent monodisperse emulsions at the same volume fraction. The oil droplet distribution of CF + 5 g kg⁻¹ GG was inclined to monodisperse, and that of XG + 10 g kg⁻¹ GG was inclined to polydisperse (Fig. 3). The result was similar to the use of β -glucan in LF mayonnaises, wherein oil droplets of FF were significantly larger than in this study, perhaps because the homogenization speed was fast.¹⁶ McClements²⁷ reported that the smaller the droplet size, the greater the extent of a three-dimensional gel network with the more open the structure formed at the lower oil volume fractions, leading to larger emulsion viscosity. This phenomenon of oil droplet reticular and network formation can be observed in Fig. 3(b) and (c).

Particle analysis

Figure 4(a) shows particle size distribution of LF mayonnaise with different polysaccharide gums at optimum ratios. Average diameters of control, XG + 10 g kg⁻¹ GG and CF + 5 g kg⁻¹ GG were 7.49, 12.44 and 27.78 μ m, respectively. The large diameter of the CF + 5 g kg⁻¹ GG group results from a second large-sized group of particles (Fig. 4(b)). This was not observed in light or electron micrographs and may result from CF fibers that were not incorporated into the emulsion. The smaller-diameter peak in the CF + 5 g kg⁻¹ GG group was about the same size as the control (FF)

Figure 3. Electron micrographs of low-fat mayonnaise with different polysaccharide gums at optimum ratios: (a) control (FF); (b) XG + 10 g kg⁻¹ GG; (c) CF + 5 g kg⁻¹ GG (3500 $\times$).

peak in accordance with the light and SEM micrographs (Figs 1 and 3). Although the particle size of the control (FF) was lower than that of the XG + 10 g kg⁻¹ GG group, there was no difference in K values (Table 2). This observation was similar to data from Liu *et al.*⁹ Moreover, the diameters of oil droplets are only one indicator of the viscosity and emulsion stability.²³

Sensory evaluations

Sensory evaluation scores of mayonnaise samples are shown in Fig. 5. The appearance, aroma, taste, greasiness and overall acceptance score of XG + 10 g kg⁻¹ GG was not ($P > 0.05$) different from the control. However, the scores for appearance, taste and overall acceptance of CF + 5 g kg⁻¹ GG group were lower ($P < 0.05$) than those for the control (FF) and the XG + 10 g kg⁻¹ GG group. This might be due to the rougher

Figure 4. (a) Particle size distribution. (b) Volume mean diameter of low-fat mayonnaise with different polysaccharide gums at optimum ratios.

Figure 5. Sensory evaluation of mayonnaise samples. Means in columns followed by different letters in the same sensory parameter test are significantly different ($P < 0.05$).

appearance of the CF + GG group compared to other groups (data not shown). In this study, the overall acceptability scores of commercial mayonnaises evaluated by the same sensory panel were approximately 5 (data not shown). Therefore, it is reasonable that the sensory attributes with scores higher than 5 are considered acceptable. The overall acceptance of LF mayonnaises formulated with the XG + 10g kg^{-1} GG was 5; hence it was acceptable. On the other hand, the CF content influenced taste and appearance scores so that overall acceptability of CF + 5g kg^{-1} GG was lower than other mayonnaise groups. There were no ($P > 0.05$)

differences in aroma, greasiness or flow parameter values in the CF + 5g kg^{-1} GG group compared to FF control (Table 2 and Fig. 5). Although the CF + 5g kg^{-1} GG group contains sufficient dietary fiber to be considered as a health food (Table 3), the question remain how to improve the mouthfeel of high-fiber LF mayonnaises.

CONCLUSION

The objective of this study was to investigate whether XG-GG and CF-GG could be optimized as fat replacers in formulations of LF mayonnaise. The XG + 10g kg^{-1} GG and CF + 5g kg^{-1} GG groups had similar rheological properties to the control (FF) and could approximately halve the caloric values and increase total dietary fiber content (near 3g kg^{-1}). They also increased brightness value compared to the control. Scanning electron micrographs showed that the network of aggregated droplets in LF treatments contained a large number of interspaced voids of varying dimensions. The oil droplets were polydispersed in XG + 10g kg^{-1} GG, whereas they were monodispersed in CF + 5g kg^{-1} GG. In the comparison of sensory evaluation of LF treatments with commercial mayonnaises, there were no significant differences in any sensory scores among XG + 10g kg^{-1} GG and control. However, there were significant differences in appearance, taste and overall acceptance between CF + 5g kg^{-1} GG and control. Hence XG + 10g kg^{-1} GG were further applied to develop as a functional ingredient of LF salad dressings.

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