The effect of different emulsifiers on the eggless cake properties containing WPC

Mohammad Khalilian Movahhed¹ · Mohebbat Mohebbi¹ · Arash Koocheki¹ · Elnaz Milani²

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Abstract The possibility of complete replacement of egg proteins with whey protein concentrate (WPC) and improvement in quality by different emulsifiers was evaluated. Three emulsifiers, including polyglycerol ester (PGE), distilled mono glyceride (DMG) and lecithin were used to bake eggless cakes, containing 8% (w/w) WPC. The response surface analysis was applied to study the effect of emulsifiers on the eggless cake properties. The emulsifiers, individually and interactively, improved the properties of the eggless cakes significantly. The PGE and DMG decreased the batter density, however lecithin increased it. All emulsifiers increased the porosity and volume of the eggless cakes, but decreased the hardness and gumminess of crumb and improved the sensory acceptance. The indices used for optimization of formulation were water activity, moisture content, hardness, gumminess, volume, porosity and total acceptance. The optimum quality of the eggless cake can be achieved from a combination of 0.5 PGE, 0.25 DMG and 0.5% lecithin. The experimental and predicted responses of the optimized eggless cake had a good resemblance.

Keywords Eggless cake · Emulsifier · Optimization · Physical and sensory properties

Introduction

Wheat flour, sugar, egg and fat (depending on the type of cake) are the important ingredients in cake baking. Egg is being replaced with other protein sources, due to its cholesterol, high price and dietary issues. Furthermore, the vegans, vegetarians, and egg allergy consumers are not willing to use egg (Ashwini et al. 2009).

The structure of bakery products is a highly important parameter for consumers. Proteins are essential in many food formulations as foaming ingredients. Egg protein is essential in bakery products which has great influence on the structure of its batter for its appearance and texture (Tan et al. 2015). Because of such functional roles, it would be difficult to reduce or substitute egg in cake completely (Ashwini et al. 2009). Some alternative proteins have been used in bakery products, including whey protein concentrate, soy milk, bovine plasma, cowpea protein isolates, kidney bean, field pea and amaranth protein isolates, and white lupine protein (Rahmati and Mazaheri Tehrani 2015; Shao et al. 2015; Shevkani et al. 2015; Shevkani and Singh 2014). The use of other protein sources for the substitution of egg in cake formulations can be investigated; nevertheless, other materials need to be used to create favorable characteristics caused by egg proteins (Rahmati and Mazaheri Tehrani 2014). Emulsifiers are materials that have been used in the baking industry commonly. They provide the aeration and gas bubble stability during the baking process (Turabi et al. 2008). Various emulsifiers and hydrocolloids as egg replacers to produce a cake with a high quality and acceptability have been tried to consumers.

Whey protein is the main source of globular proteins used in the food industry for its function as an emulsifying

✉ Mohebbat Mohebbi
mohebbatm@gmail.com; m-mohebbi@um.ac.ir

¹ Department of Food Science and Technology, Faculty of Agriculture, Ferdowsi University of Mashhad (FUM), Mashhad, Iran

² Department of Food Processing, Iranian Academic Center for Education Culture and Research, Mashhad, Iran

and foaming agent (Bernard et al. 2011). The foaming ability of whey protein is considerably related to β -lactoglobulin content and its degree of denaturation (Shao and Kao 2009). The whey protein ability to stabilize foams, is due to the connections between the monomeric and polymeric types and the foaming and stabilizing properties could be derived from the monomeric and polymeric forms, respectively (Damodaran 1997).

Monoglycerides manufactured for bakery applications, consist of plasticized, powdered, hydrated and distilled monoglycerides. The alpha crystal of monoglyceride emulsifiers is usually utilized in cake batter production to help the emulsification of the shortening in the aqueous phase as well as incorporating air into the lipid phase (Orthofer 1997). Compared to emulsifiers such as monoglycerides, polyglycerol ester is found to have an advantage in providing the long time stability of the whipping properties and good texture of crumbs, making the emulsifier an excellent choice for cake mixes (Norn 2008). Lecithin is widely used as an emulsifier in the food industry. It is usually an inexpensive and accessible emulsifier used for the reduction of stickiness as well as controlling the wetting of dry ingredients and emulsification properties (Orthofer 1997). Different researchers have recently attempted to replace partial or whole egg in cake. Some of these studies include Turabi et al. (2008), used an emulsifier blend and different hydrocolloids in the egg yolk-free rice cake, Ashwini et al. (2009) studied the possibility of the complete replacement of egg in cake with different hydrocolloids and emulsifiers. Also, Lee et al. (1991) used the fresh, frozen and spray-dried bovine plasma instead of egg white and whole egg at a high-ratio in layer cake. Arozarena et al. (2001) examined the total substitution of white lupine protein, emulsifiers and xanthan for egg in yellow cake. Miller and Setser (1983) applied xanthan to partially replace egg white in angel food cake. Rahmati and Mazaheri Tehrani (2014) investigated the effect of different emulsifiers on the eggless cake containing soy milk. Singh et al. (2015) used jambolan fruit pulp and xanthan gum incorporation on the physicochemical, antioxidant and sensory properties of gluten-free eggless rice muffins. Singh et al. (2016) developed eggless gluten free muffins from rice flour containing black carrot dietary fibre concentrate by using xanthan gum. Jyotsna et al. (2007) used whey protein concentrate (WPC) and investigated the rheological and baking properties of eggless cake. They reported that the incorporation of 20% WPC created the optimum properties of eggless cake. Therefore the aims of this study were to analyze the influence of different emulsifiers (PGE, DMG and lecithin) on the quality and physicochemical properties of the eggless cake containing WPC and the response surface

analysis was applied to study the effect of emulsifiers on the properties of eggless cake.

Materials and methods

Materials

Commercial wheat flour (protein content of 9%, Rezai Co. Golestan, Iran), three different types of emulsifiers including PGE (poly glycerol ester), DMG (distilled mono glyceride) (Palsgard., Denmark) and lecithin (pure., DAEJUNG., South Korea), WPC (whey protein concentrate) with a protein content of 80%, (Kian Meshkat Co., Tehran, Iran), double acting type baking powder (Behfar Khorak Co., Gilan, Iran), milk powder (free fat., Pegah Co, Mashhad, Iran), glycerol (87% purity., Merck Co., Germany) were purchased. Sugar, sunflower oil, salt and vanilla were procured from local market.

Preparation of the emulsifier gels

The emulsifier gels were prepared using the dispersions of emulsifiers at a ratio of 1:4:3 (emulsifier:water:glycerol). The dispersions were heated under continuous agitation to 65 and 80 °C for PGE and DMG, respectively. The emulsifier gels were obtained after cooling.

Cake formulation and preparation

The following formulation was used for the preparation of the eggless cake: wheat flour 100 g; liquid sunflower oil, 40 g; sugar powder 80 g; salt 1 g; baking powder 3 g; vanilla 1 g; milk powder 12 g; WPC 8 g; glycerol 4 g; water 82 mL; emulsifiers: PGE and DMG 0.25 g and 0.5 g, and lecithin 0.5 g and 1 g. Wheat flour, baking powder and vanilla were sifted thrice, where sugar powder and liquid sunflower oil were creamed at a speed level of 3 with a Philips mixer (350 W, Canada) for 3 min. 40 ml of water, emulsifier gel, salt, WPC and milk powder were added and mixed at a speed of 1 for 1 min and at a speed of 3 for 4 min. Finally, flour and the remaining water were added, mixed to homogeneous at a speed of 1 for 1 min and 3 for 2 min. Then, the cake batter was transferred into a 5-cm-diameter cake mold (50 g each) and baked for 23 min at 180 °C using an electrical oven (LG, model MP. 9484SR, Germany). The cakes were cooled after baking at room temperature for 60 min and then packed in sealed plastic bags and stored at room temperature.

Three independent batches of the samples were prepared for analyses and sensory evaluation. The samples were prepared and packaged in plastic bags and stored at room temperature for 24 h to equilibration.

Analytical methods

Batter density

The density of the cake batters was measured by dividing the weight of known volume of the cake batter by the weight of an equal volume of water (Rahmati and Mazaheri Tehrani 2014).

Moisture content

The moisture content of the eggless cakes was measured gravimetrically by drying the samples in an oven (Memmert. UNB400, Germany) at 105 °C.

Water activity

The water activity of the eggless cakes was determined at 25 °C using a water activity meter (Rotronic Hygrolab). The samples were analyzed in triplicate 1 day after baking and the means were reported.

Cake volume

The cakes volume was determined 1 day after baking using seed displacement method (AACC 2000). Three samples were analyzed from each formulation.

Imaging

Imaging was performed for the batter and the final eggless cake. A digital camera (canon EOS 1000D) in a specific chamber of imaging was used for image acquisition. The batter images were captured using an Olympus BX41 microscope equipped with a DP12 digital camera (Olympus Corporation, Japan). The freshly prepared eggless cake batters, without any emulsifiers and with the maximum levels of different emulsifiers, were examined by placing a drop of batter on a slide and pressed with a thin cover slip.

Porosity

The porosity of the eggless cake crumbs was evaluated by image processing methods. For porosity measurements, the eggless cakes were cut vertically through their center and the images were captured by a digital camera. The images were processed and analyzed by Image J v1. 47. RGB color system is not useful to confirm segmentation. The initial step is to convert the original RGB image to gray scale. Color Space Converter plugin was applied. Afterwards, the gray images contrast was enhanced by 0.4% of the saturated pixels. Segmentation was carried out by applying the manual thresholding, where the grey level threshold was

chosen by determining each of the peaks of the repetition histogram and subsequently the valleys between them, looking for the lowest point of this tilt and adjusting manually (Crowley et al. 2000). The threshold intensity used to binary images ranged from 130 to 190. Next, the porosity of the eggless cakes were expressed.

Texture analysis

The texture analysis of the cake crumbs (hardness and gumminess) were evaluated using a texture analyzer (TA-PLUSE, Lioyd. Instrument Ltd., UK). The crumbs of the cake samples were cut into cubes of 2 cm in diameter and compressed upto 50% of their original height at a speed of 2 mm/sec using a cylindrical probe (50 mm in diameter) and a 50 N load cell (Tan et al. 2011).

Sensory evaluation

Sensory analysis of the eggless cakes was performed by a group of fifteen trained personnel, composed of graduate students. The sensory evaluation of crust color, aroma, taste, crumb color, internal texture appearance, texture softness, adhesiveness, and total acceptability was done using 5-point hedonic scale (1, very low to 5, very high).

Experimental design and statistical analysis

Response surface methodology (RSM) was used to investigate the effects of the process variables on various responses such as moisture content, water activity, volume, porosity, sensory total acceptability, color.

A 3-factor face-centered central composite design (CCD) was created and analyzed by RSM using Design Expert (6.0.2, Minneapolis, MN). PGE (%; X_1), DMG (%; X_2), and lecithin (%; X_3) were intended as the independent variables. The independent factors and their levels are shown in Table 1. Reproducibility of this method was assessed by six replications of the center point.

The data were fitted to a second-order polynomial model and the regression coefficients were achieved. The generalized second-order polynomial model was as follows:

$$Y = B_0 + \sum_{i=1}^3 B_i X_i + \sum_{i=1}^3 B_i X_i^2 + \sum_{i=1}^2 \sum_{j=i+1}^3 B_{ij} X_i X_j \quad (1)$$

where B_0 , B_i , and B_{ij} were the coefficients of the regression and X_i and X_j were the independent factors. The mathematical models for each response were appraised to use a multiple regression method. The significance of each response variable and equation parameter was analyzed by using analysis of variance (ANOVA). The effects of the process variables on the responses were analyzed at a

Table 1 Experimental design for eggless cake production, including the independent variables and the responses evaluated

No.	PGE (%)	DMG (%)	Lecithin (%)	DN (g/ml)	MC (%)	aw	VOL (cm ³)	POR (%)	HAR (n)	GUM (n)	SEN
1	0.50 (1)	0.50 (1)	0.00 (−1)	1.0301	20.07	0.784	117.00	38.3	1.765	0.955	4.12
2	0.00 (−1)	0.50 (1)	1.00 (1)	1.1235	20.51	0.807	108.00	40.16	2.418	1.084	2.10
3	0.25 (0)	0.25 (0)	0.50 (0)	1.0588	20.32	0.8125	110.10	37.8	2.330	0.801	3.95
4	0.25 (0)	0.00 (−1)	0.50 (0)	1.070	21.36	0.808	107.00	35.682	2.505	0.998	3.71
5	0.25 (0)	0.25 (0)	0.00 (−1)	1.046	21.54	0.82	97.50	29.4777	5.209	2.121	3.20
6	0.25 (0)	0.25 (0)	1.00 (1)	1.1245	20.65	0.82	113.00	35.436	2.225	0.940	3.22
7	0.25 (0)	0.25 (0)	0.50 (0)	1.0542	20.75	0.801	114.15	36.52	2.294	0.801	4.21
8	0.50 (1)	0.25 (0)	0.50 (0)	1.051	18.62	0.772	118.50	39.912	1.704	0.693	4.80
9	0.00 (−1)	0.50 (1)	0.00 (−1)	1.0615	21.56	0.816	98.50	35.7	6.905	2.714	2.40
10	0.25 (0)	0.25 (0)	0.50 (0)	1.054	20.51	0.8022	113.90	37.9	1.749	0.800	4.12
11	0.50 (1)	0.00 (−1)	0.00 (−1)	1.0593	21.70	0.828	88.50	31.84	5.477	2.313	2.90
12	0.25 (0)	0.50 (1)	0.50 (0)	1.0402	20.14	0.797	111.50	37.912	1.694	0.653	3.91
13	0.50 (1)	0.50 (1)	1.00 (1)	1.106	18.62	0.78	127.00	39.868	1.362	0.522	3.30
14	0.25 (0)	0.25 (0)	0.50 (0)	1.0481	20.75	0.812	112.10	36.25	1.710	0.893	3.90
15	0.50 (1)	0.00 (−1)	1.00 (1)	1.124	19.83	0.811	112.50	41.704	2.978	1.231	2.90
16	0.25 (0)	0.25 (0)	0.50 (0)	1.054	20.77	0.812	113.50	37.5	1.810	0.951	4.15
17	0.00 (−1)	0.25 (0)	0.50 (0)	1.101	20.34	0.801	103.50	36.6	3.351	1.307	3.80
18	0.25 (0)	0.25 (0)	0.50 (0)	1.057	20.35	0.8119	111.09	36.45	1.801	0.951	3.85
19	0.00 (−1)	0.00 (−1)	0.00 (−1)	1.1203	20.45	0.803	89.50	24.205	5.809	2.382	1.02
20	0.00 (−1)	0.00 (−1)	1.00 (1)	1.161	20.69	0.813	110.00	42.5365	2.798	1.113	2.01

DN batter density, MC moisture content, aw water activity, VOL eggless cake volume, POR eggless cake porosity, HAR eggless cake hardness, GUM eggless cake gumminess, SEN total acceptance of eggless

confidence level above 95% ($p < 0.05$). The backward elimination procedure with $\alpha = 0.05$ was selected to remove the non-significant terms.

Results and discussion

Response surface analysis

The quadratic models were selected as a suitable mathematical model for all responses. ANOVA showed that models were highly significant ($P < 0.01$) for all responses. Moreover, lack-of-fit was not significant for the response surface models at 95% confidence level, indicating that models were adequately accurate for predicting the responses (Table 2).

Batter density

The mixing operation incorporated air into the batter and resulted into formation of small bubbles. By entrapping these bubbles, the emulsifiers could enhance this function. The small air bubbles act as the initial core to create porosity during baking. The results showed that PGE and DMG decreased the batter density, but lecithin had a

reverse effect (Table 2). Figure 1 shows the interactive effects of PGE and DMG, as well as PGE and lecithin on batter density. PGE and DMG had a synergistic effect on batter density (Fig. 1a). Lecithin increased batter density, however, PGE had an antagonistic effect (Fig. 1b). Figure 2 shows the photomicrographs of different batters containing the emulsifiers. Figure 2a indicates the eggless cake batter without any emulsifiers in which large and small air bubbles can be observed. The air bubbles are not uniformly distributed throughout the batter. The photomicrograph of the eggless cake batter with 0.5% DMG (Fig. 2c) showed an increase in the number of small air bubbles. The photomicrograph of the batter containing 0.5% PGE (Fig. 2b) displays many air bubbles and small-sized air bubbles which were relatively more than those of the batter with DMG. Figure 2d is the photomicrograph of the batter containing 1% lecithin. It shows the air bubbles are of uniform size and appear to be evenly distributed throughout the batter and a number of air bubbles are less than those of the other photomicrographs.

The low density of cake batter indicates that more air is incorporated into the batter (Turabi et al. 2008). As shown in Fig. 2, the lower density of the eggless batter containing PGE and DMG than those without emulsifiers may be attributed to the existence of many small bubbles in the

Table 2 Actual second-order regression coefficients for response variable

Regression coefficient	DN	MC	aw	VOL	POR	HAR	GUM	SEN
b_0	1.06	20.57	0.81	111.53	36.69	2.09	0.88	4.13
b_1	−0.02	−0.47	−6.500E−003	5.40	1.24	−0.80	−0.29	0.67
b_2	−0.017	−0.31	−7.900E−003	5.45	1.60	−0.54	−0.21	0.33
b_3	0.032	−0.50	−2.000E−003	7.95	4.02	−1.34	−0.56	−0.011
b_1^2	0.017	−0.90	−0.018	—	2.79	—	—	—
b_2^2	—	—	—	—	—	—	—	−0.45
b_3^2	0.027	0.72	0.016	−5.38	−3.01	1.60	0.65	−1.05
b_{12}	6.190E−003	−0.47	−0.010	4.50	—	−0.76	−0.30	—
b_{13}	4.790E−003	−0.31	—	—	−1.42	0.57	0.17	−0.19
b_{23}	—	—	—	−3.12	−2.77	—	—	−0.26
R^2	0.98	0.8799	0.8343	0.9572	0.9385	0.9468	0.9729	0.9669
R^2 (adj)	0.97	0.8098	0.7578	0.9375	0.9026	0.9222	0.9604	0.9476
Lack-of-fit F value	4.29	4.21	1.94	2.68	4.60	3.50	4.03	2.79
Lack-of-fit p value	0.0639	0.0665	0.2404	0.1466	0.0560	0.0921	0.0707	0.1384

b_0 constant term, b_1 linear coefficient of PGE, b_2 linear coefficient of DMG, b_3 linear coefficient of lecithin, b_1^2 quadratic coefficient of PGE, b_2^2 quadratic coefficient of DMG, b_3^2 quadratic coefficient of lecithin, b_{12} interaction effect of PGE and DMG, b_{13} interaction effect of PGE and lecithin, b_{23} interaction effect of DMG and lecithin

Fig. 1 Effects of, **a** PGE and DMG in 0.5 (g) of lecithin, and **b** PGE and lecithin in 0.25 (g) of DMG on batter density

batter and the high density of the eggless batter containing lecithin was to the presence of less air bubbles.

Moisture content and water activity

The results showed that the linear effects of the emulsifiers in the order of PGE, DMG and lecithin, in addition to the interactive effects of PGE and DMG, and PGE and lecithin were significant on the moisture content of the eggless cake (Table 2).

The interactive effects of PGE and DMG, and PGE and lecithin on eggless cake moisture content are shown in Fig. 3. The results depicted that PGE, in low ratio, maintained the moisture content of the eggless cake, but reduced in high ratio. DMG and lecithin decreased the moisture content of eggless

cake. Emulsifiers were reported to assist in retaining moisture of a product through binding with water molecules (Baker 1997). Nevertheless, in this study, due to the increasing volume and formation of a spongy structure as the result of using the emulsifiers, compression was reduced and water loss increased during baking. Arozarena et al. (2001) reported that baked products with higher volume had a lower moisture content. Rahmati and Mazaheri Tehrani (2014) stated that the eggless cakes containing lecithin and distilled glycerol mono stearate (DGMS) had a higher moisture loss than those comprising sorbitan mono stearate (SMS).

The results showed the linear and interaction effects of PGE and DMG were significant on water activity of eggless cake (Table 2). The results also indicated that increase in PGE and DMG decreased water activity. Application of

Fig. 2 Photomicrographs of different batters contain emulsifiers. **a** without emulsifier, **b** PGE, **c** DMG, **d** lecithin and Crumb texture of eggless cake with different emulsifiers, **e** without emulsifier, **f** PGE, **g** DMG, **h** lecithin

emulsifiers led to an increase in porosity and a decrease in moisture content; therefore water activity decreased, too. As stated before, an increase in the water activity of the eggless cake occurred when emulsifiers were used, due to the higher ability to bind and retain water.

Eggless cake volume

The results showed the linear effects of PGE, DMG and lecithin allied to the quadratic effect of lecithin and the interactive effects of PGE and DMG, and DMG and lecithin on volume of cake were significant (Table 2).

Figure 3 also demonstrated that the significant interactive effects of PGE and DMG, and DMG and lecithin on volume of cake. It was observed that the increase in emulsifier levels had increasing effects on the eggless cake volume. Emulsifiers had ability to bind the ingredients together, create oil in water emulsions and help to entrap air in the batter (Dickinson and Yamamoto 1996; Sakiyan et al. 2004). The oil in water emulsion created a stable wall around air bubbles. On the other hand, emulsifiers increased the viscosity of batter (Norn 2008). Therefore, high viscosity increased the trapping of air bubbles in batter. Arozarana et al. (2001) reported mono glyceride and lecithin increased the volume of the eggless cake and the effect of mono glyceride was higher than that of lecithin. Turabi et al. (2008) also reported the mixture of emulsifiers increased the porosity and volume of the rice cake.

Porosity

The results showed the linear effects of PGE, DMG and lecithin coupled with the quadratic effect of PGE and lecithin besides the interactive effects of PGE and lecithin, and DMG and lecithin were significant on the eggless cakes porosity (Table 2).

Figure 3 also illustrates the interactive effects of PGE and lecithin, and DMG and lecithin on the porosity of the eggless cakes. ANOVA and Fig. 3 showed the rise in PGE increased the porosity of the eggless cakes. DMG also had an increasing effect on the percentage of porosity which was more significant compared with the PGE effects. Among the emulsifiers, lecithin had greater effects on the porosity of the eggless cake. Figure 2 also shows the crumb texture of the eggless cake with different emulsifiers. In the eggless cakes free of emulsifiers, the crumb texture was compact and the percentage of porosity was less than that of the other samples (Fig. 2e). The porosity of the texture of the cakes was affected by the trapped air during mixing, water vaporization and the CO₂ produced from the baking powder. Double-acting baking powder releases some air bubbles during mixing and some carbon dioxide and gas cells would be produced by heating throughout the baking process. In the batter containing PGE, it was observed that air bubbles sizes were smaller than those of the other samples (Fig. 2b). During heating, CO₂ and water vapor are produced and the initial air bubbles in the batter, act as a core for the formation of pores in the final crumb of the cakes. As more initial bubbles form, the final cake will have a more porous and uniform texture (Fig. 2f). DMG increased the trapped bubbles in the eggless cake batters, too, thus increasing the porosity and uniformity of the eggless cakes crumbs (Fig. 2g); however, the number of air bubbles was low in the batter resulted from lecithin, but lecithin created a more porous batter than the other emulsifiers. Rahmati and Mazaheri (2014) stated that lecithin caused the highest viscosity in batter compared to the other emulsifiers they used. Turabi et al. (2008) have also stated that higher viscosity values of batters improved the cake structure and this resulted in higher volumes. Therefore, in the samples which contained lecithin, porosity was high but non-uniform (Fig. 2h).

Fig. 3 Effects of **a** PGE and DMG in 0.5 (g) of lecithin, and **b** PGE and lecithin in 0.25 (g) of DMG on eggless cake moisture content, **c** PGE and DMG in 0.5 (g) of lecithin, and **d** DMG and lecithin in

0.25 (g) of PGE on eggless cake volume, and **e** PGE and lecithin in 0.25 (g) of DMG, and **f** DMG and lecithin in 0.25 (g) of PGE on porosity of eggless cakes

Evaluation of the coefficient estimate of the factors (Table 2) and graphs indicated that PGE and DMG had antagonistic interactions with lecithin, such that PGE and DMG had negative effects on porosity when used by lecithin, nonetheless the shape of the pores was more uniform than samples with no emulsifiers (Fig. 2).

Texture analysis of the eggless cake

The results showed the linear effect of the emulsifiers and the quadratic effect of lecithin and also the interactive effect of PGE and DMG, PGE and lecithin were significant on the eggless cakes hardness (Table 2).

Fig. 4 Effects of **a** PGE and DMG in 0.5 (g) of lecithin, and **b** PGE and lecithin in 0.25 (g) of DMG on eggless cake hardness, **c** PGE and DMG in 0.5 (g) of lecithin, and **d** PGE and lecithin in 0.25 (g) of

DMG on eggless cake Gumminess, and **e** PGE and lecithin in 0.25 (g) of DMG, and **f** DMG and lecithin in 0.25 (g) of PGE on total acceptance of eggless cakes

Figure 4 shows that the rise in the percentage of the emulsifiers decreased the hardness of the eggless cakes. The comparison of the hardness and volume of the eggless cake showed a negative correlation ($R^2 = -0.86$) between them. Similar results for the use of emulsifiers in cake (Arozarena et al. 2001; Zhou et al. 2011). As observed in

Fig. 4a, PGE and DMG, in low percentage, had negligible effects on hardness. By increasing both of them, hardness decreased so that the minimum hardness was observed in the maximum percentage of PGE and DMG. Lecithin, in low amount (0.5%), had the larger effect on decreasing the hardness of the eggless cakes than higher values (Fig. 4b).

Arozarena et al. (2001) also reported low level of the soy lecithin had a decreasing effects on hardness.

The results showed the linear effect of the emulsifiers, the quadratic effect of lecithin and the interactive effect of PGE with DMG and lecithin on the gumminess were similar to those observed for hardness (Table 2). Increasing PGE and DME led to a decrease in the gumminess of the eggless cake. Although lecithin decreased the gumminess, but had an improving effect at higher levels. Since gumminess is a function of hardness, the results of different emulsifier's effects on gumminess were to some extent similar to those observed for hardness of the eggless cake. Figure 4 also shows the interaction between PGE with DMG and lecithin on the gumminess. The interactive effect of PGE and DMG in high levels was maximized, while had a slight effect on the gumminess of the eggless cakes (Fig. 4c), however, an opposite trend was observed for lecithin. The maximum effect of lecithin on the decrease of gumminess was in low levels (Fig. 4d), but in high levels, its effect decreased and changed to the increase of gumminess. Other researcher stated that different emulsifiers had decreasing effects on cake gumminess (Kumari et al. 2011; Sowmya et al. 2009).

Total acceptance of the eggless cake

The results showed the linear effect of PGE and DMG, the quadratic effect of DMG and lecithin, and the interaction of lecithin with PGE and DMG on the total acceptance scores of the eggless cakes (Table 2).

Figure 4e indicates an increase in PGE increased the total acceptance scores. The reason for this increase may be attributed to the high volume and low hardness and gumminess that were created by PGE. Lecithin, up to 0.5%, increased the total acceptance scores of the eggless cake that was in agreement with the volume and textural properties of the eggless cakes. High levels of lecithin led to a decrease in the total acceptance of the eggless cakes because of the dark color of the crust, high color intensity of the crumb and the taste and aroma of the soy lecithin.

Figure 4f shows the interactive effect of DMG and lecithin on the total acceptance of the eggless cake. The results showed as DMG increased, total acceptance scores increased, too. It should be mentioned that in high levels of DMG, its effects were not significant. Kumari et al. (2011) reported that addition of sodium stearoyl-2-lactylate (SSL) and carboxymethyl cellulose (CMC) brought about significant improvements in the quality characteristic of the cake baked with sunflower oil. Rahmati and Mazaheri Tehrani (2014) studied the influence of different emulsifiers including lecithin on the eggless cakes containing soy milk, observed the effect of lecithin on the sensory overall acceptability was maximized at 0.5% level.

Optimization

The results showed that the levels of different emulsifiers to achieve the optimum quality of the eggless cake constituted of 0.5% PGE, 0.25% DMG and 0.5% lecithin. The RSM values for each characteristics under the optimum conditions were predicted as 19.3% for moisture content, 0.78 for water activity, 118.79 cm³ for cake volume, 41.13% for Porosity, 1.1 N for hardness, 0.51 N for gumminess and total 4.79 for acceptance. The *p* values more than 0.05 (*p* > 0.05) confirmed that RSM was capable of predicting for this process.

Conclusion

Generally, total replacement of egg by different replacers does not create a good quality cake; therefore, the combination of PGE, DMG and lecithin can produce an eggless cake containing WPC with a high quality that is acceptable for consumers. Combination of different emulsifiers improved their functional properties. The emulsifiers increased the volume, porosity and the sensory total acceptance, and decreased the moisture content, water activity, hardness and gumminess of the eggless cakes. The predicted values of each properties of the eggless cakes, which were produced by the optimum levels of the emulsifiers, were similar to the experimental results showing the predictive capability of this method. The use of high levels of PGE in combination with low levels of DMG and lecithin provided the optimum quality of the eggless cake.

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