Effect of high-pressure processing on quality and stability of green mango blended mayonnaise

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Revised: 21 April 2017 / Accepted: 26 April 2017 / Published online: 30 May 2017
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Abstract The present work was aimed to study and optimize the high pressure treated green mango blended mayonnaise in terms of oxidative and emulsion stability, as a function of technical parameters; pressure intensity, dwell period and level of green mango pulp. Mayonnaise samples were treated at different combinations of pressure (400–600 MPa), holding time (5–10 min) and level of green mango pulp (10–30%) following Box–Behnken design. Mayonnaise quality was evaluated in terms of oxidative stability and emulsion stability using response surface methodology to optimize the best possible combination among all. Analysis of variance showed that the second-order polynomial model fitted well with the experimental results. Pressure and time were the most important factors determining the oxidative stability (free fatty acids, peroxide value and anisidine value) whereas; the emulsion stability (creaming and thermal creaming) was most significantly affected by the level of green mango pulp. The optimized conditions for preparing green mango blended mayonnaise with high oxidative and emulsion stability were: 435 MPa pressure, 5 min of holding time with the addition of green mango pulp at the rate of 28%.

The product prepared at optimum conditions showed good correlations between predicted and actual values.

Keywords Mayonnaise · Green mango pulp · Oxidative stability · Emulsion stability · Response surface methodology

Introduction

Mayonnaise is a cold emulsion of egg, vinegar and oil and is probably one of the widely consumed sauces or condiments in the world today (Morales-Aizpurúa and Tenuta-Filho 2005). With increased consumption of ready-to-eat salads, mayonnaise and salad dressings have become a trendy segment of the food industry among the young population, and are growing at a faster rate not only in developed countries, but in developing countries as well (Castro-Rosas et al. 2012; Dupree and Savage 2001). Generally, it is freshly prepared by fast food manufacturers around the world; retail packs which are preserved for few days by pasteurization treatment are also available. Despite of its popularity, it is considered as unhealthy condiment, because of its high fat content and absence of vital nutrients. The market for mayonnaise is growing as different and interesting flavours and ingredients are launched, and healthy versions are being developed (McClements 2005; Chatterjee and Bhattacharjee 2015). Over the past few years, consumer awareness for health has led to utilization of natural and health promoting ingredients in mayonnaise preparation. Addition of fruit pulp into mayonnaise is the innovative concept being used by product development scientists, for its improved quality, enhanced nutritional value, health promoting properties and sensory acceptance among consumers (Izidoro et al. 2008).

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Mango is the world's most widely eaten fresh fruit and is known for its rich taste and versatility, as well as nutritional value. Mangoes are packed with vitamins, minerals and anti-oxidants and contain very few calories. Mango fruit is rich in pre-biotic dietary fiber, vitamins, minerals and poly-phenolic flavonoid antioxidant compounds and is considered a very useful remedy and energizer in Ayurveda owing to its myriad benefits that are good for the health. Mango can be used to treat diseases such as cancer and it aids in digestion because of its high fiber content. It can be eaten both raw and ripe. The unripe, raw, green mango has been used in the preparation of pickles and chutney in the Asian countries. Tart, unripe green mangoes are used in several ethnic Indian cuisines and can be effectively utilized as an ingredient in products that favour sour taste such as salad dressings, sauces, dips etc. Raw mango is an excellent source of vitamin C, which is comparatively more than ripe mangoes; due to which it is highly beneficial in strengthening immune health. It is also a good source of B vitamins that are beneficial to maintain good health and is an excellent remedy for liver disorders. The acids contained in the unripe, green mango triggers the secretion of bile and act as intestinal antiseptic (Ajila et al. 2007; Masibo and He 2009). Current trend in new product development is towards reduced fat versions and in this context various fat, protein and carbohydrate based replacers are being incorporated into mayonnaise and salad dressings (Amiri Aghdaei et al. 2014; Alu'datt et al. 2017; Bernardino-Nicanor et al. 2015; Hou-Pin et al. 2010; Mozafari et al. 2017).

To overcome the hazard associated with recent emergence of acid-tolerant pathogens and spoilage micro-organisms, mayonnaise and salad dressings processed at commercial scale requires some kind of processing treatment (Srilatha and Balasubramaniam 2005). Since, thermal processing is a heat intensive process that results in significant loss of colour and flavour components, extensive research is going on towards inclusion of non-thermal processing technologies for heat sensitive food products. Development of healthier food products has aroused due to increased consumer concerns over the use of chemical preservatives, overconsumption of fats and loss of nutritive value due to thermal processing. For such products, high-pressure processing (HPP) may be considered as an alternative method of processing. The effectiveness of high-pressure processing to increase the shelf-life and safety of these dressings, sauces and sandwich spreads without using chemical preservatives and, at the same time, maintaining its sensory and textural quality, has allowed for the expansion of HPP technology to become an effective processing technology alternative. The possibility of extending the shelf-life without giving

thermal treatment to food for prolonged periods; significantly helps to suit consumer's requirement of fresher tasting and high quality heat-sensitive foods; that are otherwise hard to process using conventional food preservation methods (Srilatha and Balasubramaniam 2005).

Addition of fruit pulp in mayonnaise has been studied by few researchers, and very little scientific information is available on use of high-pressure processing as a preservation technique for mayonnaise. The increasing popularity of mayonnaise has led to concerted efforts to explore the feasibility of using green mango pulp as a flavour and nutritious ingredient in the mayonnaise. Furthermore, high-pressure processing, which is a non-thermal processing technique can be utilized to increase the shelf-life, and at the same time to maintain the fresh like characteristics of the product. The objective of present study was to evaluate the effect of addition of green mango pulp and high pressure processing conditions on quality characteristics (oxidative stability and emulsion stability) of mayonnaise by means of response surface methodology.

Materials and methods

Materials

Green or raw mangoes of variety *Neelam* were obtained from local fruit and vegetable market of Mysore, Karnataka, India. All ingredients used in the formulation of mayonnaise that are Rice bran oil, eggs, vinegar, mustard powder, sugar, salt and white pepper were obtained from local market of Mysore. All the chemicals used for analysis of mayonnaise were of analytical grade.

Preparation of green mango pulp

A homogeneous pulp of washed and peeled green mangoes was obtained by mixing in a laboratory Mixer Grinder (Phillips) for 1 min and sieved through 60 mesh sieve. The pulp was stored in aluminium polyester laminates and kept at -18°C until used.

Process for green mango blended mayonnaise preparation

Mayonnaise was prepared with rice bran oil substituted at different levels with green mango pulp (10, 20 and 30%). The formulations were prepared with the following ingredients: Rice bran oil, eggs, vinegar, green mango pulp, salt, sugar, mustard powder and white pepper according to method of Kishk and Elsheshetawy (2013) with slight

Table 1 Coded and actual levels of independent variables

Process variables	Code	Coded levels		
		−1	0	+1
Pressure (MPa)	X1	400	500	600
Holding time (minutes)	X2	5	7.5	10
Green mango pulp (%)	X3	10	20	30

modification. The proportions of eggs, vinegar, salt, sugar, mustard powder and white pepper were 12, 6, 1, 0.5, 0.3 and 0.2%, respectively. The mayonnaise emulsions were prepared using a laboratory blender at constant speed. First, the aqueous phase ingredients were mixed for 1 min and then, slowly rice bran oil was added with continuous blending for 2 min in order to form a uniform emulsion.

Experimental design and model fitting

The effect of adding green mango pulp and high pressure processing on the quality (emulsion stability, free fatty acids, peroxide value and anisidine value) of mayonnaise was studied. The quality characteristics of mayonnaise were evaluated using a response surface model with a box–behken design with three factors (pressure, holding time and green mango pulp) at three levels. The minimum and maximum values of independent variables were established from the preliminary experiments and available literature. The experimental design with their coded and actual levels of all the three factors is presented in Table 1. Seventeen experimental runs, with five replications on the central point of box–behken design were performed. The experiments were randomized in order to minimize the effects of unexplained variability in the observed responses due to extraneous factors. All determinations of the response variables were performed in triplicate. Statistical significance of the second-order polynomial equation was determined by analysis of variance (ANOVA) at 1 and 5% level of significance. The effect of independent variables at linear, interactive and quadratic level was studied and regression coefficients were determined, which were then utilized for generating response surfaces. Design expert 9 (Stat Ease Inc.) software was used for simultaneous optimization of the multiple responses. Optimal levels of pressure, holding time and green mango pulp were determined by numerical optimization for all response variables. The constraints were set to get the coded value of variable between lower and upper limits for an optimum response. A weight was assigned to each goal to adjust the shape of its particular desirability function. The optimum formulations were selected for calculating the predicted values of response variables using the prediction equations derived by response surface methodology (RSM).

High pressure processing of mayonnaise samples

Green mango mayonnaise samples (30 g approx.) hermetically sealed in linear low density polyethylene pouches, were loaded onto the pressure chamber for processing and treated at different HPP conditions (pressure and time) according to a box–behken design of three selected factors (Table 2) in a pressure vessel constructed from stainless steel with a 2.5 L working capacity with maximum design operating pressure of 800 MPa (Stansted fluid power ltd., Stansted, UK). Poly ethylene glycol was used as pressure transmitting fluid. The chamber containing poly ethylene glycol was hydraulically pressurized to reach the required operating pressure. The operating temperature in the chamber was kept constant at room temperature (25 °C). The time to reach the desired pressure was less than 90 s, and the depressurization time was less than 10 s. HPP-treated samples were recovered and subsequently kept at low temperature of 4–6 °C until required for full analysis.

Product quality analyses

Quality parameters assessed for HPP treated mayonnaise were: emulsion stability, oxidative stability (free fatty acids, peroxide value and anisidine value) and microstructural analysis. Samples for oxidative stability determinations were stored at −20 °C until analyzed.

Determination of emulsion stability

Emulsion stability was determined in terms of creaming and thermal creaming as described by Rahmati et al. (2014) with slight modification. To determine creaming value at room temperature, 20 ± 1 g of each sample was transferred into conical bottom, cylindrical polycarbonate tubes of 50 ml capacity and was then centrifuged at 5000 rpm for 20 min in a laboratory centrifuge (MPW350R MED Instruments, Poland). The emulsion creaming at room temperature was determined by following equation:

$$\%H = H/H_0 \times 100$$

where %H is the percentage of creaming, H is the height of the cream separated from emulsion and H_0 is the initial emulsion height in the container.

Thermal creaming was determined by following the same method, but samples were incubated in a water bath at 80 °C for 60 min before centrifugation.

Lipid extraction from mayonnaise

The mayonnaise was gently mixed prior to sampling. Thirty grams of mayonnaise samples were poured into

Table 2 Experimental matrix based on box–behnken design with corresponding response variables

Exp. no.	Independent variables				Response variables*		
	Pressure (MPa)	Holding time (min)	Green mango pulp (%)	Free fatty acids (%)	Peroxide value (meq/kg fat)	<i>p</i> -Anisidine value (mmol/kg)	Thermal creaming value (%)
1	−1	−1	0	0.121	1.999	2.994	8.0608
2	+1	−1	0	0.242	3.109	3.991	12.0997
3	−1	+1	0	0.165	2.681	3.225	9.1248
4	+1	+1	0	0.251	3.183	5.325	12.1022
5	−1	0	−1	0.124	2.312	4.002	6.9059
6	+1	0	−1	0.198	3.008	5.033	11.8431
7	−1	0	+1	0.069	1.901	2.773	11.6887
8	+1	0	+1	0.156	3.018	4.734	14.5448
9	0	−1	−1	0.113	2.217	4.04	6.6044
10	0	+1	−1	0.111	2.567	4.258	6.9444
11	0	−1	+1	0.078	2.006	2.595	11.3778
12	0	+1	+1	0.095	2.302	4.105	11.9886
13	0	0	0	0.168	2.092	3.932	9.2948
14	0	0	0	0.161	2.085	3.948	9.4531
15	0	0	0	0.163	2.121	3.954	9.8123
16	0	0	0	0.153	2.087	3.929	9.321
17	0	0	0	0.151	2.127	3.991	9.3247

* Values of experimental observations are average of 3 determinations

50 ml centrifuge tubes, the samples were then frozen at −20 °C for 24 h and thawed for 2 h at 4 °C, the freeze–thaw cycle was repeated two–three times to break the emulsion. Two milliliters of water was added and the mixtures were centrifuged at 4000 rpm for 20 min. The separated lipid phase was stored in closed glass flasks at −20 °C until analyzed (Lagunes-Galvez et al. 2002).

Determination of oxidative stability of mayonnaise

The progression of oxidation was examined by determining free fatty acids (FFA), peroxide values (PV) and *p*-anisidine values (p-AV).

Free fatty acids

AOAC (1990) method was used to determine FFA content of mayonnaise. Ten g of oil extracted from mayonnaise was taken in a 250 ml conical flask, and 100 ml of hot neutralized alcohol was added into it. The mixture was shaken to dissolve the fat. It was then titrated against 0.1 N NaOH with phenolphthalein as an indicator. FFA value was calculated by the expression as:

$$\text{Free fatty acids (\%oleic acid)} = \frac{\text{Titre value} \times \text{Normality of NaOH} \times 0.282}{\text{Weight of sample taken}} \times 100.$$

Peroxide value

For Peroxide value, 1 g of oil extracted from mayonnaise was taken in a conical flask, 25 ml of solvent was added and the air above the liquid was displaced with CO₂. Then 1 ml of potassium iodide solution was added, allowed to stand for 1 min, 35 ml of water was added and the liberated iodine was titrated with 0.1 N sodium thiosulphate solution using starch as an indicator (Ranganna 2001).

$$\text{PV} \left(\frac{\text{meq}}{1000 \text{ g fat}} \right) = \frac{(\text{Sample titre} - \text{Blank titre}) \times \text{Normality of sodium thiosulphate}}{\text{Weight of fat taken}} \times 1000$$

p-Anisidine value

For anisidine value, 0.5 g of extracted oil was taken in a 25 ml volumetric flask and dissolved in iso-octane. The

volume of the mix was made up to 25 ml. The absorbance (A) of the oil mixture was taken in a spectrophotometer (UV-Shimadzu 1601) against pure iso-octane at 350 nm in 1 cm cell. Then, 5 ml of fat solution was pipette out in a test tube and 1 ml of *p*-anisidine solution was added and absorbance (B) was measured at 350 nm after 10 min (AOCS 1992).

$$\text{Anisidine value} \left(\frac{\text{mmol}}{\text{kg}} \right) = \frac{25 \times 1.2(B - A)}{\text{weight of sample}}$$

Image analysis of some selected mayonnaise samples

Microstructure analysis of mayonnaise samples was performed by optical microscopy. The glassy flat surface was coated with a drop of mayonnaise sample which was evenly spread over the surface and placed on the stage of Inverted Microscope Eclipse (Nikon, Japan). The focus knob was adjusted to get clear view of the field. The pictures of the mayonnaise microstructure at 100× were obtained by a digital camera connected with the microscope.

Statistical analysis

Experimental data of each determination were adjusted to a second order complete polynomial model, and coefficients were determined for every term of the model. Prediction of the response variable was given by the following model:

$$y = b_0 + \sum_{i=1}^k b_i x_i + \sum_{i=1}^k b_{ii} x_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^k b_{ij} x_i x_j.$$

Analysis of variance (ANOVA), coefficient of determination (R^2), and lack of fit of model were determined using the statistical program, Design expert 9 (Stat Ease Inc.). Statistical significance of the model and model variables were determined at the 5% level of significance ($p < 0.05$).

Results and discussion

Model fitting

The effects of pressure, holding time and green mango pulp on responses namely, free fatty acids, peroxide value, anisidine value and emulsion stability of mayonnaise is presented in Table 2. The coefficients depicting functional relationship between independent variables and responses are shown in Table 3. The independent and dependent variables were fitted to the second-order response surface model and tested for lack of fit on the regression model. All

the responses under various combinations of seventeen runs were analyzed for analysis of variance (ANOVA). The statistical analysis showed that the models were adequate because they have satisfactory values of R^2 for all the responses and model significance. Results indicated that lack-of-fit was non-significant for all the response variables. The response surfaces were selected based on the significant interaction terms between the two variables within the experimental range.

Effect of pressure, holding time and green mango pulp on free fatty acids

Regression analysis showing the effect of different level of pressure, holding time and green mango pulp on free fatty acids of mayonnaise is given in Table 4. The functional relationship between the independent and dependent variables was fitted into a model using second order polynomial equation. The Model F value implied that the model was significant and there was only a 0.01% chance that a 'Model F value' could occur because of noise. The coefficient of determination (R^2) of the model was 0.9778, which further indicated that the model was suitable for adequately describing the real relationships among the selected variables (Table 3). A second-order polynomial model for the free fatty acids of green mango blended mayonnaise imply that not only linear terms of pressure, holding time and green mango pulp significantly affected the free fatty acids of mayonnaise, but also quadratic terms of these independent variables. Moreover, no significant interactions were found between two independent variables. Positive sign in front of the terms indicates synergistic effect, whereas negative sign indicates antagonistic effect. Considering the free fatty acids at the medium level of independent variables, it was found that free fatty acids increased with increasing level of pressure and holding time but decreased with increasing concentration of green mango pulp. The positive coefficient of pressure at quadratic level suggests a minimum FFA percentage at centre and it increases with increase in level of pressure whereas, a negative coefficient of green mango pulp at quadratic level shows a maximum FFA concentration at centre and it decreases with increase in level of green mango pulp. An increase in free fatty acids of mayonnaise could be due to effect of high pressure processing on unsaturated fatty acids. Majority of scientific studies on oxidation stability is confined to meat and dairy products and very little or no scientific data is available on oxidative stability of high-pressure processed mayonnaise and salad dressings. An acceleration of lipid oxidation was observed in high-pressure processed meat products but is comparable to that of cooked product (Orlien et al. 2000; Beltran et al. 2003; Wiggers et al. 2004; Tuboly et al. 2003).

Table 3 Estimated coefficients of the fitted second order polynomial model, representing the relationship between the responses and the independent variables

Source	Free fatty acids (%)		Peroxide value (meq/kg fat)		<i>p</i> -Anisidine value (mmol/kg)		Thermal creaming value (%)	
	Coefficient	<i>p</i> value	Coefficient	<i>p</i> value	Coefficient	<i>p</i> value	Coefficient	<i>p</i> value
Intercept	0.16	<0.0001	2.10	<0.0001	3.95	<0.0001	9.44	<0.0001
X ₁	0.046*	<0.0001	0.43*	<0.0001	0.76*	<0.0001	1.85*	<0.0001
X ₂	0.0085	0.0730	0.18*	<0.0001	0.41*	<0.0001	0.25	0.0934
X ₃	−0.019*	0.0025	−0.11*	<0.0001	−0.39*	<0.0001	2.16*	<0.0001
X ₁ X ₂	−0.0088	0.1688	−0.15*	<0.0001	0.28*	<0.0001	−0.27	0.1918
X ₁ X ₃	0.00325	0.5865	0.11*	0.0006	0.23*	<0.0001	−0.52*	0.0253
X ₂ X ₃	0.00475	0.4323	−0.013	0.4728	0.32*	<0.0001	0.068	0.7234
X ₁ ²	0.037*	0.0003	0.46*	<0.0001	0.16*	<0.0001	1.46*	<0.0001
X ₂ ²	−0.00098	0.8657	0.18*	<0.0001	−0.23*	<0.0001	−0.56*	0.0173
X ₃ ²	−0.059*	<0.0001	−0.0063	0.7261	0.025	0.1643	0.34	0.0968
R ² value	0.9778		0.9971		0.9991		0.9879	

X₁—Pressure, X₂—Holding time, X₃—Green mango pulp* *p* ≤ 0.05**Table 4** Analysis of variance (ANOVA) for the fitted second-order polynomial model

Process variables	F value			
	Free fatty acids (%)	Peroxide value (meq/kg fat)	<i>p</i> -Anisidine value (mmol/kg)	Thermal creaming value (%)
Total individual effect				
Pressure	4.415*	70.674**	168.59**	72.62**
Holding time	0.192	13.258**	73.72**	4.08*
Green mango pulp	3.438*	3.933*	59.74**	75.00**
Combined effect of variables at				
Linear level	5.285**	67.978**	308.07**	167.54**
Quadratic level	5.285**	38.989**	14.42**	27.69**
Interactive level	0.115	5.169*	40.13**	3.54*

**, * Significant at 1 and 5% level of significance, respectively

F_{3,16} = 5.29 (1%) and 3.24 (5%); F_{4,16} = 4.77 (1%) and 3.01 (5%)

Effect of pressure, holding time and green mango pulp on peroxide value

The effect of processing conditions and level of green mango pulp on the peroxide value of mayonnaise is shown in Table 2. The peroxide value is an important parameter as it affects the quality of final product (Calligaris et al. 2007). It is clear from analysis of variance (ANOVA) that pressure is the major parameter affecting the peroxide value of mayonnaise followed by holding time and green mango pulp. Regression model (Table 4) for the peroxide value showed a significant effect of linear and quadratic terms of pressure, holding time and green mango pulp. As the pressure and holding time was increased, peroxide

value of the mayonnaise was found to increase as expected. Peroxide value was also significantly affected by pressure, holding time and green mango pulp at interactive level. Significant negative interaction between pressure and holding time suggests that the level of one of the predictors can be increased while that of other decreased for constant value of the peroxide value whereas, positive coefficient of interaction between pressure and green mango pulp suggests a minimum peroxide value at centre point and it increases with increase or decrease of both the independent variables from centre point. The positive coefficients of pressure and holding time at quadratic level suggest that the minimum peroxide value at centre and it increases with increase or decrease in parameter level. Lipid systems are

the most pressure sensitive biological components (Rivalain et al. 2010), since lipid assemblies are governed by hydrophobic interactions that are very susceptible to high pressure. Pressure treatment had a little effect on lipid oxidation below 300 MPa, but increased linearly at pressures above this value (Cheah and Ledward 1995). Similar trend was observed in ultra high pressure homogenized almond milk where higher values of hydroperoxide index was observed in UHPH-treated samples than in untreated or heat-treated (Valencia-Flores et al. 2013). Response

surfaces for the peroxide value, showing significant interactions between independent variable are depicted in Fig. 1a, b.

Effect of pressure, holding time and green mango pulp on *p*-anisidine value

p-Anisidine value measures the secondary oxidation products formed on decomposition of hydroperoxides. Anisidine value together with peroxide value is a good indicator of

Fig. 1 Response surface plots showing the effect of **a** pressure and holding time on peroxide value, **b** pressure and green mango pulp on peroxide value, **c** pressure and holding time on *p*-anisidine value,

d pressure and green mango pulp on *p*-anisidine value, **e** holding time and green mango pulp on *p*-anisidine value, **f** pressure and green mango pulp on thermal creaming of mayonnaise

oxidative quality of fat. Analysis of variance for the anisidine value of green mango blended mayonnaise (Table 2) shows that value was significantly affected by variable levels of pressure, holding time and green mango pulp. The anisidine value of green mango blended mayonnaise which ranged between 2.595 and 5.325 mmol/kg, was found to be a function of linear and quadratic terms of pressure and holding time. The level of green mango pulp affected anisidine value at linear level. Pressure and holding time showed a direct relation with anisidine value whereas, the green mango pulp showed an inverse relation with anisidine value at linear level. The anisidine value was significantly ($p < 0.01$) affected by interactions between the three independent variables. The coefficients of significant interactions between pressure-holding time, pressure-green mango pulp and holding time-green mango pulp were positive indicating a minimum anisidine value at centre point and it increases with increase or decrease of both the independent variables from centre point. The total effect of variables on anisidine value of green mango flavoured mayonnaise is given in Table 4. Response surfaces showing the significant interactions between pressure, holding time and green mango pulp on anisidine value of green mango blended mayonnaise are shown in Fig. 1c, d and e.

Effect of pressure, holding time and green mango pulp on emulsion stability (thermal creaming)

Emulsion stability was determined in terms of creaming (at room temperature) and thermal creaming (at high temperature), which refers to phase separation due to upward rise of fat globules due to differences in density between the dispersed and the continuous phases (McClements 2009). But, on evaluation, no cream separation was observed in all the experiments at room temperature, therefore, thermal creaming value was taken as a response for measuring emulsion stability. Under the given set of experiments the thermal creaming value varied from 6.604 to 14.545% (Table 2). The maximum value of thermal creaming was observed with a combination of pressure—600 MPa, holding time—7.5 min and green mango pulp—30% and minimum with a combination of pressure—500 MPa, holding time—5 min and green mango pulp—10%. The green mango pulp and pressure showed significant positive linear ($p \leq 0.01$) as well as quadratic ($p \leq 0.01$) effects on the thermal creaming value of mayonnaise (Table 4). The only significant interaction was found between pressure and green mango pulp, a negative coefficient of which indicates that the level of one of the predictors can be increased while that of other decreased for constant value of the thermal creaming. The negative coefficient of holding time at quadratic level suggests a maximum thermal creaming value at centre and it decreases with increase in level of holding time. The decrease in

emulsion stability may be attributed to the increased amount of green mango pulp (aqueous phase) and resultant dilution effect due to it. The interaction between pressure and green mango pulp is depicted in response surface (Fig. 1f).

Optimization of high-pressure processed green mango blended mayonnaise

The objective of the study was to get the optimized condition where the best product can be obtained among the experiments performed. The optimized condition could be a single point or a range of points in which all the possible combinations would yield desired results. So, to obtain optimized conditions numerical optimization technique was adopted using Design Expert 9 Stat-Ease Inc., Minneapolis, USA. While using any optimization technique some constraints have to be decided which sets the guidelines to get the desired results. The response values and the analysis of the models gave the valuable information in deciding the constraints for independent variables and responses. An acceptable compromise was made within the variables and based on this, optimization was carried out and 14 solutions were obtained, out of which the one that suited the criteria most, was selected. The mayonnaise obtained following optimized conditions i.e. pressure level at 435 MPa, holding time of 5 min. with green mango pulp at the rate of 28%, had free fatty acids of 0.0705%, peroxide value of 1.785 meq/1000 g fat, anisidine value of 2.379 mmol/kg and thermal creaming of 10.066%. The result was compared with the predicted responses from the model equations. The experimental and predicted values of green mango blended mayonnaise were found to be not statistically different ($p > 0.05$), indicating a good agreement with model conditions for predicting optimum response values.

Micro-structural analysis of mayonnaise

Microstructures of mayonnaise samples are depicted in Fig. 2. Control (without high-pressure treatment) and sample treated at 400 MPa showed a fine, homogenous, compact and well dispersed oil-in-water emulsion with small and even size of fat globules whereas, the sample treated at 600 MPa showed a coarse, less compact and loose structure with large sized and uneven fat globules as observed in micrograph.

Conclusion

It was observed that the oxidative stability of mayonnaise, evaluated in terms of free fatty acids, peroxide value and *p*-anisidine value, showed a direct relationship with pressure

Fig. 2 Microstructural analysis of green mango blended mayonnaise **a** control (untreated), **b** treated at 400 MPa, **c** 500 MPa and **d** 600 MPa

and holding time. All the values increased with increase in the level of pressure and holding time but were within the acceptable limits. Whereas, the emulsion stability, measured in terms of thermal creaming was affected negatively with the increased level of green mango pulp on account of dilution effect by the aqueous phase of green mango pulp. Analysis of variance showed that the second order polynomial model fitted well into the experimental data. The optimum formulation for best quality product in terms of high oxidative and emulsion stability was obtained with a combination of pressure level at 435 MPa, holding time of 5 min with green mango pulp at the rate of 28%.

Acknowledgements Thanks are due to Director, Defence Food Research Laboratory, Mysore, India, for providing necessary facilities to carry out research. The financial support from ICAR, New Delhi, under Foundation Course for Agricultural Research Services, is highly acknowledged.

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