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308 Lasani Town, Sargodha Road, Faisalabad - Pakistan
Mob: +92 300 3008585, Fax: +92 41 8815544
E-mail: editorpjn@gmail.com

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Effects of Two Emulsifiers on Yield and Storage of Flaxseed Oil Powder by Response Surface Methodology

Khamis Ali Omar, Liang Shan, Xiaoqiang Zou, Zhihua Song and Xingguo Wang*
Lipid Science and Technology Laboratory, School of Food Science and Technology, Jiangnan University, 1800 Lihu Road, Wuxi, Jiangsu, P.R. China

Abstract: Response Surface Methodology (RSM) was used to establish optimum conditions for Flaxseed Oil (FO), soy lecithin and xanthan gum to yield stable Flaxseed Oil Droplet (FOD) and high Microencapsulation Efficiency (M.E.E). Gum arabic and maltodextrin were used at constant ratio of 1:1. Flaxseed oil loading (20-35%), lecithin (1-2%) and xanthan gum (0.1-0.4%) were studied regarding their effects on emulsion and the spray dried powder. Results indicated response surface models significantly fitted to all response variables studied. Regression models describing variations of responses of FOD and M.E.E showed high coefficient of determination (R^2) of 0.9963 and 0.9944 respectively. Overall numerical optimization predicted desirable system attainable by combined 10% (w/w) each arabic gum and maltodextrins, 22.78% (w/w) flaxseed oil loading, 1.14% (w/w) soy lecithin and 0.10% (w/w) xanthan gum, which in turn resulted into FOD of 446.9 nm, M.E.E of 92.3% and strong physical barrier towards oxidation during 10 weeks of storage tests.

Key words: Flaxseed oil droplet, soy lecithin, microencapsulation efficiency, flaxseed oil loading and xanthan gum

INTRODUCTION

Today the world demands foods with specific nutrients that can help human beings to stay in good health and enjoy extended life span. Bioactive compounds such as omega-3s (Eicosapentaenoic Acid (EPA) and Docosahexaenoic Acid (DHA)) help body for its normal growth and to fight against different kinds of diseases. Omega-3s fatty acids are essential for growth and development and have been associated with the prevention and treatment of heart disease, arthritis, inflammatory, autoimmune diseases and cancer (Simopoulos, 1999). In humans, omega-3s fatty acids have also been used to suppress cancer-associated cachexia and to improve the quality of life (Hardman *et al*., 2000).

The highest amount of omega-3s for oil seeds is found in flaxseeds (Bozan and Temelli, 2008), the seed from the flax plant (*Linum usitatissimum* L.) which is a member of the Linaceae family. The plant is native to West Asia and the Mediterranean, where it has been cultivated since at least 5000 BC as the source of linen fibre, yet today it is mainly grown for its oil (Berglund, 2002; Oomah, 2001).

Omega-3 fatty acid found in flaxseed and Flaxseed Oil (FO) is called Alpha-linolenic Acid (ALA). FO usually contains greater than 50% of ALA. Consuming flaxseed oil is one good way to increase the omega-3 fatty acids in the diet as most societies nowadays are known to generally consume plenty of omega-6 fatty acids in processed foods, margarine and vegetable oils and absolute amounts of omega-3 fatty acids in the diet are too low (Choo *et al*., 2007). ALA has 18 carbon atoms in its backbone and can be converted to EPA by the liver by addition of two carbon atoms (Newton, 1996). EPA, in turn, can be converted to DHA.

However, FO has rather low stability which is mainly due to its high amount of ALA. As one among the members of polyunsaturated fatty acids, omega-3 fatty acids if serious measures could not be taken during its processing and storage can easily undergo oxidation and hence results in rancidity (Shen and Wijesundera, 2009). Lipid oxidation during storage or food processing usually causes a deleterious effect on human health (Frankel, 1998) since it can lead to rancidity (Gordon, 1991) and defective nutrition due to degradation products such as reactive oxygen species (Guardiola *et al*., 2002; Esterbauer *et al*., 1991; Sanders, 1983). Protection of lipid oxidation is a critical factor to food quality and shelf-life of edible oils, and microencapsulation of oils has been widely adopted as an approach to address this issue. Lipid encapsulation may be useful to retard lipid auto-oxidation (Matsuno and Adachi, 1993; Kolanowski *et al*., 2006).

RSM is an empirical modeling approach for determining the relationship between various process parameters and has an advantage of less time-consumption than other approaches required to optimize a process (Mirhosseini *et al*., 2008a,b).

The aim of the present study was to use two emulsifiers (gum arabic and lecithin) as an approach to encapsulate flaxseed oil and study their effects on different environmental storage conditions. It is well known that

gum arabic is a very excellent emulsifier but due to its high cost, its use is limited in food industry. Different researchers have been tried and are trying to use substitutes of gum arabic or to mix them with it in different ratios in order to overcome the cost. The study used gum arabic and maltodextrins at a ratio of 1:1, and then added a little amount of lecithin and xanthan gum to increase the stability of emulsion and high yield of microencapsulation efficiency. The results are well pronounced and are good starting point for other microencapsulation approaches.

MATERIALS AND METHODS

FO was supplied by Heng Cheng Natural Perfumery Oil Refinery Company, Jiangxi China. Percentages of fatty acids in FO used were: C16:0; 5.50%, C18:0; 3.85%, C18:1; 19.87%, C18:2; 15.69% and C18:3; 52.35%. Gum arabic powder was supplied by Sinopharm Chemical Reagent Co., Ltd, Shanghai. Maltodextrin with a Dextrose Equivalent (DE) of 18 was purchased from Xiwang Starch Co. Ltd, Shandong China. Xanthan gum was supplied by Zibo Shunda Biotechnology Co. Ltd, Shandong China. Xanthan gum was used to increase viscosity of the emulsion. Soy lecithin was originally manufactured by Germany and supplied by Wuxi Always Light Industry Science and Technology Co. Ltd., Jiangsu China. Soy lecithin was used for the purpose of aid emulsifying ability with gum arabic. Sodium salicylate, sodium citrate, isooctane, 95% ethanol and other chemical reagents were bought from Sinopharm Chemical Reagent Co., Ltd, Shanghai China. All reagents were of analytical grade.

Emulsion preparation: Emulsions were prepared by keeping constant amount of gum arabic and maltodextrin (ratio of 1:1). Experimental design of the emulsion preparation and Flaxseed Oil Powder (FOP) were shown in (Table 1). FO, soy lecithin and xanthan gum were varied at different concentrations (Table 2) to study their effects on performance of the resulting emulsion and spray dried powder. Gum arabic, xanthan gum and maltodextrin were separately dissolved in de-ionized water and then the three resultant solutions were mixed together. For complete dissolution, the solution was kept 12 hours to ensure complete hydration. The O/W emulsions were prepared by slowly mixing FO into the soy lecithin solution and then finally into prepared solution by using an electric mixer for approximately 5 min to form coarse emulsion which was then homogenized by a homogenizer (model JHG-Q54-P60, Shanghai China) set at a pressure of 24 MPa. The emulsion was homogenized twice at the same pressure to obtain a stable emulsion.

Table 1: Coded levels for independent variables used in experimental design for emulsion preparation and microencapsulation of flaxseed oil powder

		Coded level		
Variables	Coded Xi	-1	0	1
Concentration of lecithin (%w/w)	X_1	0.5	1.25	2.0
Concentration of oil loading (%w/w)	X_2	20	27.5	35
Concentration of xanthan gum (%w/w)	X_3	0.1	0.2	0.3

Table 2: Box-Behnken design for the optimization of flaxseed oil powder microencapsulation

Runs	X_1 (%w/w)	X_2 (%w/w)	X_3 (%w/w)	FOD (nm)	M.E.E (%)
1	1.25	20	0.3	322.1	90.1
2	0.5	35	0.2	648.7	71.4
3	0.5	20	0.2	440.5	84.4
4	1.25	35	0.1	454.3	75.8
5	1.25	20	0.1	336.6	93.2
6	2	20	0.2	322.7	92.1
7(c)[1]	1.25	27.5	0.2	382.9	83.6
8(c)[1]	1.25	27.5	0.2	379.7	84.8
9(c)[1]	1.25	27.5	0.2	392.9	84.6
10(c)[1]	1.25	27.5	0.2	401.9	84.2
11	1.25	35	0.3	471.8	76.6
12	0.5	27.5	0.3	549.5	80.2
13	2	27.5	0.1	352.7	84
14	0.5	27.5	0.1	552.1	80.4
15	2	27.5	0.3	375.8	84.6
16	2	35	0.2	370.8	74.8
17(c)[1]	1.25	27.5	0.2	398	83.9

(c)[1], center point

Average droplet size: The average droplet size was determined by dynamic light scattering using a Zetasizer Nano-ZS90 (Malvern Instruments, Worcestershire, UK). The particle size of the emulsions was described by cumulants mean diameter.

Fatty acid composition: Fatty acids composition for FO was determined using gas chromatography (model GC-14B Shimadzu) of Fatty Acid Methyl Esters (FAMEs). The resultant data were processed by a computer using N2000 software.

pH measurements: The pH values of the emulsions were measured by means of a glass pH electrode (Metler Toledo, Delta 320 pH) and the emulsion pH was maintained at 6.10 by using potassium diphosphate pentahydrate.

Spray drying: Spray drying was conducted using a high speed spray dryer (model QZ-5, Shanghai China). The drying chamber diameter was 1.5 m, the inlet and outlet air temperatures were set at 180/190°C and 85±3°C respectively. The emulsion was fed into the dryer by a peristaltic pump at a flow rate of 2.2L/h and an inlet pressure of 0.350 MPa during spraying.

Moisture content: The moisture content of FOP was determined according to A.O.C.S. Recommended Practice Ca 2d-25 (AOAC, 1998).

Microencapsulation Efficiency (M.E.E): M.E.E of the samples was determined by extracting surface and total oil in FOP. M.E.E was expressed as follows: (Ahn *et al*., 2008);

M.E.E = (Total oil-Surface oil) x 100% / (Total oil)

Surface oil determination: Surface oil of FOP was extracted for 3 h with petroleum ether with a boiling range of 30-60°C (Partanen *et al*., 2002) and the extracted oil was determined gravimetrically. Triplicate measurements were performed.

Total oil content determination: Total oil determination was done by method reported (Partanen *et al*., 2002).

Storage tests: Each FOP sample was spread into a petridish to achieve a depth of approximately 0.5 cm. The samples were then placed in humidified chambers (desiccators in dark) in which relative humidifies were controlled at constant RHs respectively of 44% and 54.4%, using standard saturated salts of K_2CO_3 and $MgNO_3$ solutions prepared both at 25°C (Teunou *et al*., 1999; Greenspan, 1977). Powder samples were mechanically mixed for 5 min every 3 days to assure even exposure to the environment. Triplicate samples were drawn every week for 10 weeks of storage. The study was done in a special controlled room with a temperature set at 28±2°C.

Peroxide and *p*-anisidine values determination: The surface oil powder was measured after gentle shaking according to the methods adopted by (Ahn *et al*., 2008). In the case of encapsulated oil, extraction using Pont method was used as adopted by (Ahn *et al*., 2008) and extraction was started from the encapsulated FO dried to a constant weight after free oil was extracted. To release fat from reconstituted FOP, de-emulsification reagent was used, followed by heating and centrifugation.

For preparation of de-emulsification reagent, 10 g sodium salicylate and 10 g sodium citrate were dissolved separately in double-distilled water, followed by mixing together with 18 mL n-butanol and made up to 90 mL with double distilled water. Ten grams of FOP were mixed with 20 mL water at 50°C in 125 mL Erlenmeyer flask with stopper. Then 15 mL de-emulsification reagent were added, mixture was shaken vigorously and left to stand in 70°C water bath for 6 min. The resulting mixture was centrifuged at 4000 rpm for 10 min and oxidation degree of the extracted fat was determined.

The Peroxide Value (PV) was determined by iodometric titration (Shantha and Decker, 1994) and *p*-anisidine value was determined by spectrophotometry according to A.O.C.S. Recommended Practice Cd 18-90 (AOAC, 1998). Both PV and p-anisidine analysis were carried out in triplicates.

Scanning Electron Microscopy (SEM): A Quanta-2000 (FEI Company, Netherlands) SEM was used to examine the external appearance of the particles. Examinations were made at 1200 x magnifications.

RESULTS AND DISCUSSION

Experimental design and statistical analysis: RSM was used to establish desired optimum emulsion stability and higher microencapsulation efficiency for FO in water emulsion.

Based on preliminary experiments, concentrations of soy lecithin, flaxseed oil loading and xanthan gum concentrations were studied as critical variables with significant effects on emulsion stability and microencapsulation efficiency. Also (Table 1) indicates the results obtained for the two responses. Experimental data were statistically analyzed by Design-Expert® version 7.1, (State-Ease, Inc., Minneapolis MN, USA).

The quadratic response surface analysis was based on multiple linear regressions taking into account linear, quadratic and interaction effects according to the equation below:

$$Y = b_0 + \sum a_i x_i + \sum a_{ij} x_i x_j + \sum a_{ii} x_i^2 \quad (1)$$

Where Y is the response value predicted by the model; b_0 is offset value; a_i, a_{ii} and a_{ij} are main (linear), interaction and quadratic coefficients, respectively.

The adequacy of the models was determined using model analysis; lack-of fit test and coefficient of determination (R^2) analysis. For model to be suited, R^2 should be at least 0.80 for a good fitness of a response model (Mirhosseini *et al.*, 2009).

$$\text{Z-Average} = +516.46 - 150.45x_1 + 7.5x_2 - 169.7x_3 - 1.52x_1x_2 + 14.28x_1x_3 + 1.52x_2x_3 + 25.76x_1^2 - 0.010988x_2^2 + 94.28x_3^2 \quad (2)$$

$$\text{M.E.E} = +92.59 + 19.39x_1 - 0.1024x_2 - 68.06x_3 - 0.1911x_1x_2 + 0.6667x_1x_3 + 1.3x_2x_3 - 4.6x_1^2 - 0.0171x_2^2 + 66.5x_3^2 \quad (3)$$

Analysis of Variance (ANOVA): The results of analysis of variance showed the quadratic polynomial models were adequately represented experimental data with the coefficients of multiple determinations R^2 for the responses of droplet size and M.E.E values 0.9963 and 0.9944 respectively.

Significance of the coefficients of quadric polynomial models were shown on (Table 2). For any term in the models, a large F-value and a small P-value would indicate a more significant effect on respective response variables (Mirhosseini *et al.*, 2008a,b; Quanhong and Caili, 2005; Yuan *et al.*, 2008). Hence results showed the largest effect on oil droplet size of the formed emulsion was the linear term of flaxseed oil loading, followed by quadratic term of soy lecithin and then followed by interaction term of soy lecithin with flaxseed oil loading at $p<0.0001$. While for M.E.E, linear term of flaxseed oil loading showed largest effect, then followed by quadratic term of flaxseed oil loading and then followed by linear term of soy lecithin at $p<0.0001$.

Analysis of response surfaces

Flaxseed oil droplet size: To visualize effects of the independent variables on the dependent ones, 3-Dimensional (3D) plots of the quadric polynomial models were generated by varying two of the independent variables while holding the third as constant at the central point. (Fig. 1a, 1b and 1c) show how emulsion droplet size was affected by three independent variables.

In general, emulsion droplet size increased with an increase the flaxseed oil loading. The same effect was also reported by (Yuan *et al.*, 2008). However the increase in soy lecithin concentration had shown positive effect on lowering the emulsion droplet size as shown in (Fig. 1a) and this was significant at $p<0.0001$. But further increase of soy lecithin concentration did not positively affect the emulsion droplet size, this effect was also observed by (McSweeney *et al.*, 2008). The

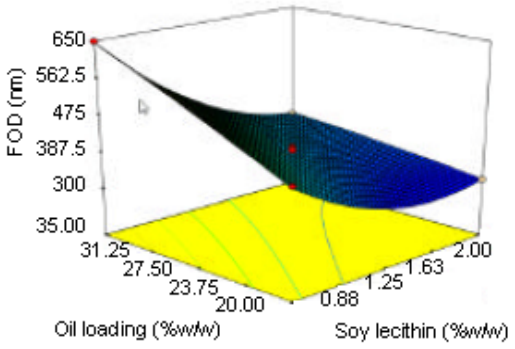

Fig. 1a: Hold xanthan gum at 0.2% (w/w)

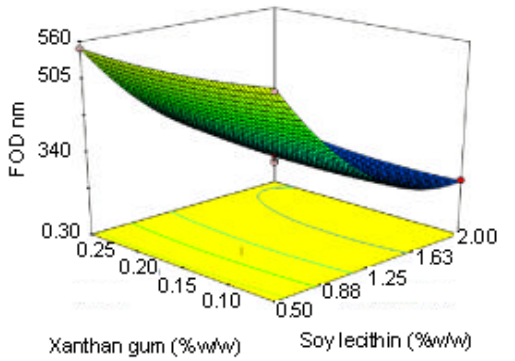

Fig. 1b: Hold oil loading at 27.5% (w/w)

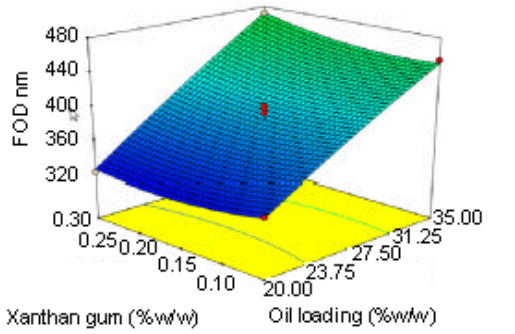

Fig. 1c: Hold soy lecithin at 1.25% (w/w)

effect of lowering the emulsion droplet size might also be influenced by the amount of gum arabic that has been used at constant ratio; hence synergistically effect might have been played between soy lecithin and gum arabic at certain concentration levels of soy lecithin.

Xanthan gum concentration had shown little effect on the emulsion droplet size; but further increase in the concentration resulted in evident increase in emulsion droplet size as shown in (Fig. 1b). But its increase was insignificant at $p<0.0001$. Xanthan gum is well known for its ability to increase the viscosity hence helps to increase the stability of an emulsion. When xanthan gum is dispersed in water system, its complex molecules

form complicated aggregates through hydrogen bonds and polymer entanglement. The presence of these active sites in xanthan gum structure provides a great water absorption capacity thereby increase in viscosity (Mirhosseini *et al*., 2009).

Microencapsulation Efficiency (M.E.E): M.E.E was shown to be strongly influenced by soy lecithin concentration and flaxseed oil loading, while for xanthan gum had also shown a little effect on it. Increasing the concentration of soy lecithin resulted in positive effect of increasing microencapsulation efficiency, but further increase of soy lecithin concentration resulted in constant value of M.E.E as shown in (Fig. 2a). This might shown that soy lecithin with the aid of gum arabic gave a strong emulsifying ability when used together. Lecithin is well known for its excellent emulsifying properties to form lamella mesophases and vesicles in aqueous media and produce lipid-protein complexes (Courthaudon *et al*., 1991). However, further an increase in flaxseed oil loading to the system resulted in lowering M.E.E as shown in (Fig. 2b and 2c). This probably due to emulsifying agents was no longer strong enough to hold more oil droplets.

Optimization procedure: Numerical optimization procedures were carried out for predicting exact optimum level of independent variables leading to desirable response goals. Optimal treatment was found via response surface plotting of the data, by compromise between optimum ranges of the two responses.
Using response optimizer, the results obtained were 22.78% flaxseed oil loading, 1.14% soy lecithin and 0.10% xanthan gum of emulsions made with fixed amount of gum arabic with maltodextrin 10% of each which had shown very high stability in stabilizing the emulsion droplet size (446.9 nm), high value of M.E.E (92.3%) and strong physical barrier towards oxidation during 10 weeks of the study at specified relative humidity.

Moisture content: The moisture content of FOP studied was 2.61%, which was low enough for its longer shelf life. The results were under the minimum moisture specification for most dried powder in the food industry which is between 3 and 4 g/100 g with water activity about 0.3 (Klaypradit and Huang, 2008).

Effects of environmental storage conditions on oxidation stability of FOP: Both Peroxide Value (PV) and p-anisidine value were used for oxidation stability study of FOP. PV measures hydroperoxide products and is a good indicator of the primary oxidation products of oils while *p*-anisidine value generally reflects the magnitude of aldehydic secondary oxidation products in oils.
PV of oil is an empirical measure of oxidation and is useful for samples that are oxidized to relatively low

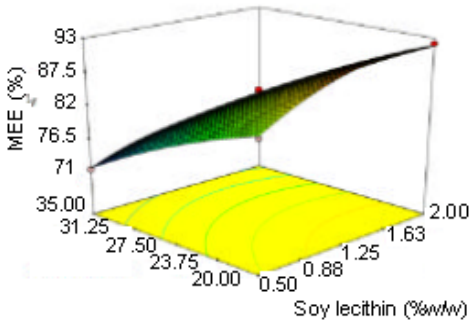

Fig. 2a: Hold xanthan gum at 0.2% (w/w)

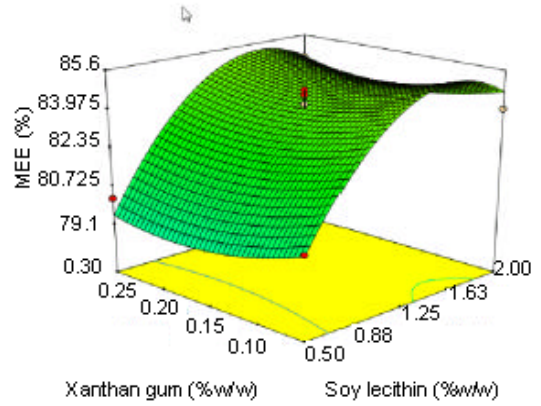

Fig. 2b: Hold oil loading at 27.5% (w/w)

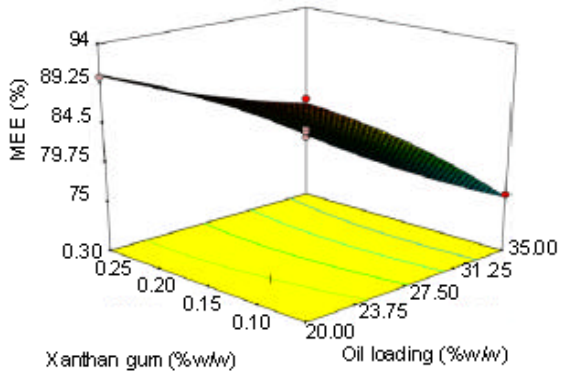

Fig. 2c: Hold soy lecithin at 1.25% (w/w)
Figures 1a-2c, keep one independent factor constant and allow the other two independent factors for variation in order to study their interaction effect.

levels. The p-anisidine test provides useful information on nonvolatile carbonyl compounds formed in oils during processing and is often used to detect secondary oxidation products (Choo *et al*., 2007).
Figure 3 and 4 show the changes in PV and p-anisidine values respectively for both encapsulated and surface oil powder of the FOP during storage study of 10 weeks at a temperature of 28±2°C and relative humidities of 44%RH and 54.4%RH.

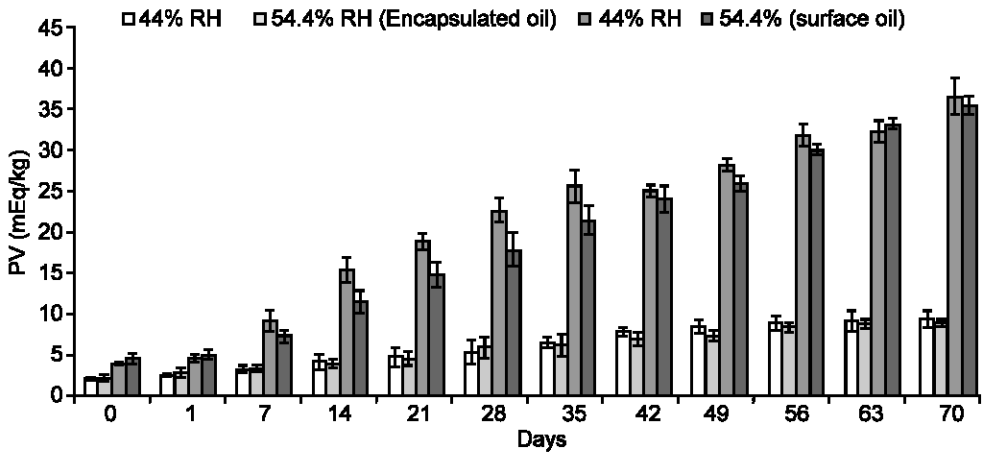

Fig. 3: PV of encapsulated and surface oil powder of the flaxseed oil powder at 28±2°C with 44%RH and 54.4%RH

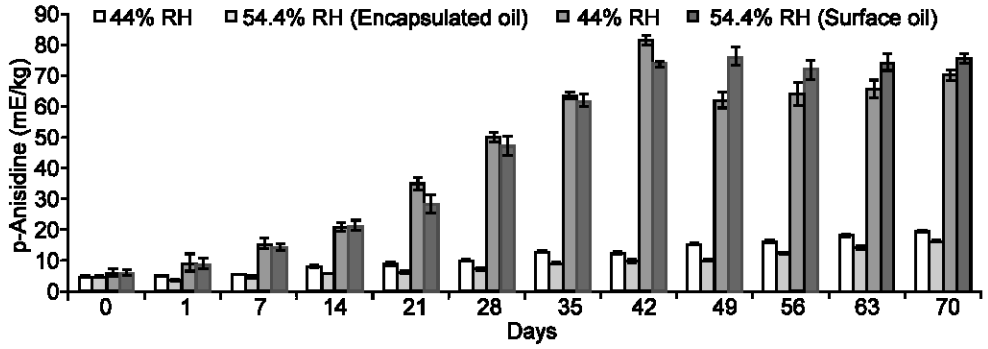

Fig. 4: p-anisidine value of encapsulated and surface oil powder of the flaxseed oil powder at 28±2°C with 44%RH and 54.4%RH

Table 3: Analysis of Variance of the regression coefficients of the fitted quadratic equations for the FOD and M.E.E of the flaxseed oil powder

	Flaxseed Oil Droplet (FOD)			Microencapsulation Efficiency (M.E.E)		
Variable	Regr. coeff.	F-value	P-value	Regr. coeff.	F-value	P-value
a_0	516.5			92.5858		
Linear						
a_1	-150.5	1072.5	1E-04	19.3944	102.13	<0.0001
a_2	7.5	497.66	1E-04	-0.1024	1048.56	<0.0001
a_3	-169.7	1	0.35	-68.0583	1.01	0.3482
Inter-action						
a_{12}	-1.5	93.02	1E-04	0.1911	10.35	0.0147
a_{13}	14.3	2.4	0.166	0.6667	0.36	0.5683
a_{23}	1.5	3.72	0.095	1.3000	8.52	0.0224
Quadratic						
a_{11}	25.8	205.33	1E-04	-4.5956	63.01	<0.0001
a_{22}	0.0	0.69	0.433	-0.0171	8.59	0.0215
a_{33}	94.3	4.4	0.074	66.500	4.17	0.0805
R^2			0.9963			0.9944
Adj R^2			0.9915			0.9872
Pred R^2			0.9812			0.9357
Lack of Fit		0.43	0.7432		2.97	0.1600

a_0 is a constant, a_i, a_{ii} and a_{ij} are the linear, quadratic and interactive coefficients of the quadratic polynomial equations, respectively

The processing procedures of the emulsion and spray drying resulted into increase of the oxidation of the FO, possibly, this was mainly contributed by spray drying where high temperature is used (Kolanowski *et al*., 2006). For the case of PV, the initial value of flaxseed oil used was 1.26 mEq/kg and then increased to 4.62 mEq/kg after spray drying. Also p-anisidine value initially was 2.45 mEq/kg and then accelerated to 6.26 mEq/kg after spray drying.

The PV of the surface oil powder gradually increased from 3.91 and 4.62 mEq/kg in first week of our study to 36.50 and 35.37 mEq/kg at 44%RH and 54.4%RH respectively. At 54.4%RH, the PV of the surface oil powder was slowly increased as compared to 44% RH. For the encapsulated powder the situation was different, the PV was seemed to be almost constant during the first three weeks and then tended to increase slowly till the end of the study. The constant low oxidation during first three weeks, showed that system was stable to protect the oil and then started to break slowly hence allowing the penetration of oxygen and increase in oxidation. PV ranged from 2.18 and 2.24 mEq/kg to 9.39 and 8.89 mEq/kg in the 10^{h} week of the study at 44%RH and 54.4%RH respectively. The storage of FOP at 54.4%RH had shown low peroxide value compared to storage at 44%RH, this may be due to microcapsules held at low RH could develop a porous or a cracked surface permitting penetration of oxygen and causing greater production of peroxides (Jimenez *et al*., 2004). The powder flow ability was changed at 6^{h} week of our study for 54.4%RH while the powder flow ability remained constant at 44%RH during the whole period of the storage study. The same change was also observed by others (Toure *et al*., 2007; Partanen *et al*., 2005).

The p-anisidine reagent reacts with oxidation products, such as aldehydes (principally 2-alkenals and 2, 4-dienals), producing a yellowish product. Hence, an increased in p-anisidine value indicates an increase in the amount of oxidation product. The rate of fat oxidation is a function of several factors, including moisture content of the product and availability of oxygen (Cho *et al*., 2003). Fig. 4 shows changes of p-anisidine value for surface and encapsulated FOP during storage. The increasing rate of p-anisidine value for surface FOP was much faster than the encapsulated FOP, the same trend was shown by the PV.

Effect of physical structure of the flaxseed oil powder sprayed dried at different temperatures: SEM micrographs of the spray dried FO at 180°C and 190°C outlet temperatures with 85±3°C each inlet temperature are shown in (Fig. 5a and 5b) respectively. A significant wrinkle on the surface was observed, possibly due to uneven shrinkage related to protein functionality change

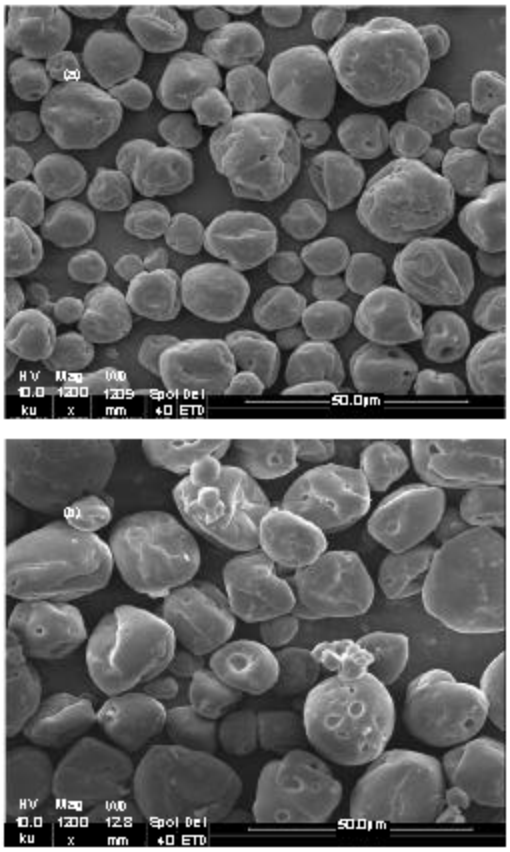

Fig. 5: (a and b) Effect of physical structure of the flaxseed oil powder sprayed dried at 180°C and 190°C inlet temperatures respectively with 85±3°C outlet temperature as observed with scanning electron microscopy at 50 µM

in the drying process, attributed to the results of mechanical stresses induced by uneven drying at different parts of the liquid droplets produced during early stages of drying, to the movement of moisture during the non-saturated surface drying period and to the effect of a surface tension-driven viscous flow (Klinkesorn *et al*., 2006). From our results, no significant changes were found for spray dying at 180°C and 190°C inlet temperatures.

Effects of storage period on physical structure of the flaxseed oil powder: Significant cracks of the FOP stored for 10 weeks at specified temperature of 28±2°C were found in both 44% and 54.4%RHs as shown in Fig. 6a and 6b respectively. But more cracks were found at 44%RH as compared to 54.4%RH, this might be explained by the fact that at low RH the moisture uptake from the product to the environment is higher and thus causes the cracks for the powders. As a result it accelerated the oxidation of the powder as it is shown in Fig. 3 and 4. At 44%RH storage of the FOP

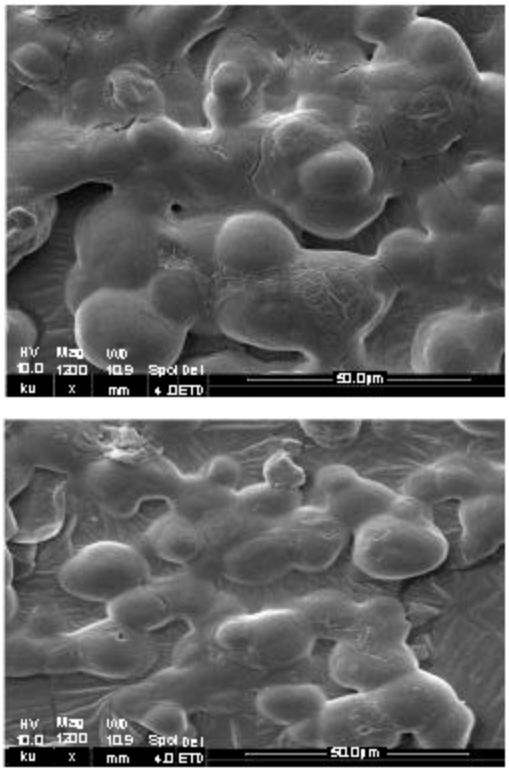

Fig. 6: (a and b) Effects of 10 weeks of storage period on physical structure of the flaxseed oil powder at 44%RH and 54.4%RH respectively at 28±2°C

more cracks were found compared to 54.4%RH and may probably accelerates higher oxidation.

Conclusion: The study has shown that second-order polynomial model was sufficient to describe and predict the responses of the oil droplet size and microencapsulation efficiency of the system within the experimental ranges. The model provided the strong stability of FOD which resulted in high microencapsulation efficiency of FOP. Gum arabic with the aid of soy lecithin had shown pronouncing effect on reducing FOD hence resulting in high microencapsulation efficiency. During storage period, FOP was strong enough to resist the environmental factors and hence resulted in low oxidation values especially for the encapsulated powder, this showed that gum arabic, maltodextrins, xanthan gum and soy lecithin provided strong effect against harsh environmental factors. On proper scaling up, the system suggested herein might be designed for industrial production of FOP for dietary supplementation of omega-3s fatty acids.

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