# Effect of Microwave heating on physico-chemical and thermal behavior of blended fat

[1]Sengar, G., [1,]*Sharma, H. K. and [2]Kumar, N.

[1]*Food Engineering and Technology Department, Sant Longowal Institute of Engineering and Technology, (Deemed-To-Be-University), Longowal – 148 106, Sangrur, Punjab, India*
[2]*Agricultral Process Engineering Department, College of Agricultural Engineering and Technology, Anand Agricultural University, Godhra-389001, Gujarat, India*

## Abstract

A blend of hydrogenated palm kernel oil and butter (3:2) was selected and exposed to microwave heating for 5, 10 and 15 min at low and high power settings. The treated samples were analyzed for physico-chemical properties viz. peroxide value (PV), color values, free fatty acid content (FFA), iodine value (IV) and C18:2/C16:0 ratio and subjected to "Differential Scanning Calorimetry" (DSC) to examine the correlation among thermal properties and the changes in their physico-chemical parameters. FFA, PV, and color value reflected a noticeable increase by 16.6%, 19.27% and 78.5%, respectively with the increase in microwave power and time setting where as IV and C18:2/C16:0 ratio reflected decline in their values by 19.27% and 21.5% respectively. The experimental data highlighted that DSC curve parameters like peak areas and peak height had significant and positive correlation at all the settings of microwave time and power with FFA, whereas significant and negative with IV. The data showed non-significant and positive correlation with PV at all the heating times and power settings of microwave. C18:2/C16:0 ratios reflected their negative and significant correlation with peak areas at high power setting whereas color value revealed a positive and significant correlation with peak B area at both power settings. The physico-chemical and thermal behavior reveales the blended fat stability during microwave heating operations.

## Introduction

Microwave (MW) heating represents a progressive technology with increasingly wider range of usage in food industry. It has become common appliance/utility tool due to its fast heating facility which makes it convenient to use in restaurants and houses. Microwave heating is also used in industrial processes for the final drying of fried potatoes and biscuits. Several investigations have focused on the effects of microwave heating on animal (Yoshida *et al.*, 1992) and vegetable fats (Yoshida *et al.*, 1995; Cossignani *et al.*, 1998). The effects of microwave heating systems and conventional heating systems on vegetable oils like cotton seed oil and hydrogenated palm oil and on animal fat like butter and beef liver fat have been studied (Farag, 1994; Chu and Hsu, 2001). Influence of microwave irradiation on lipid oxidation of peanut seeds, quality characteristics of borage leaves, nutrional changes in cooked brown rice have also been reported by Jittrepotch *et al.* (2010), Dwivedy *et al.* (2013) and Jaroenkit *et al.* (2013) respectively.

The lipid oxidation is one of the major causes of food spoilage which is an economic concern to the food industry, because it leads to the development of off-flavors and off-odors in edible oils and fats constituting foods. The flavor of oxidized oils is mainly attributed to primary and secondary oxidation products (Rovellini *et al.*, 1997; Shahidi and Wanasundara, 1997). Mishra *et al.* (2010) studied the oxidative stability of physically refined rice bran oil under oven test and microwave heating conditions by absorptivity. The rate of degradation of fat during microwave heating varies with heating temperature and time, and with other domestic processing methods (e.g., frying, steaming, and roasting). During microwave heating, appropriate quality parameters can therefore be used as time-temperature indicators of quality deterioration of oils. Extensive utilization of chemicals in standard analysis procedures is a drawback in monitoring chemicals changes. Also, the complexity of methods and time-consumption can be a major drawback in industrial applications. Therefore, the instrumental methods can be involved to fasten the procedure which is desired in determining the chemical changes in fats and oils.

Differential scanning calorimetry (DSC) is

*Corresponding author.
Email: *h_sharma27@rediffmail.com*
Tel: +91 94173 84917

Table 1. Initial physico-chemical characteristics of Hydrogenated palm kernel oil, Salted butter and blended fat (3:2)

| Parameters | Composition | | |
|---|---|---|---|
| | Hydrogenated palm kernel oil | Salted butter | 3:2 blend |
| Caprylic acid, C8:0 [%] | 3.3 | 2.4 | 7.8 |
| Capric acid, C10:0 [%] | 2.4 | 3.8 | 5.6 |
| Lauric acid, C12:0 [%] | 48.2 | 5.0 | 24.1 |
| Myristic acid, C14:0 [%] | 16.2 | 11.0 | 11.8 |
| Palmitic acid, C16:0 [%] | 15.4 | 30.0 | 13.5 |
| Stearic acid, C18:0 [%] | 7.0 | 7.1 | 13.0 |
| Oleic acid, C18:1 [%] | 4.1 | 40.0 | 22.4 |
| Linoleic, C18:2 [%] | 2.0 | 0.7 | 1.8 |
| C18:2/ C16:0 | $0.108 \pm 0.0$ | $0.02 \pm 0.0$ | $0.13 \pm 0.0$ |
| Peroxide value, PV[meqO$_2$/kg lipids] | $0.46 \pm 0.1$ | $0.65 \pm 0.01$ | $0.571 \pm 0.0$ |
| Iodine value, IV | $6.8 \pm 0.0$ | $0.63 \pm 0.16$ | $14 \pm 0.32$ |
| Free Fatty Acid, FFA [%] | $0.002 \pm 0.0$ | $0.06 \pm 0.01$ | $0.018 \pm 0.0$ |
| Color value [Units] | $1.5 \pm 0.0$ | $5.2 \pm 0.0$ | $7 \pm 0.0$ |
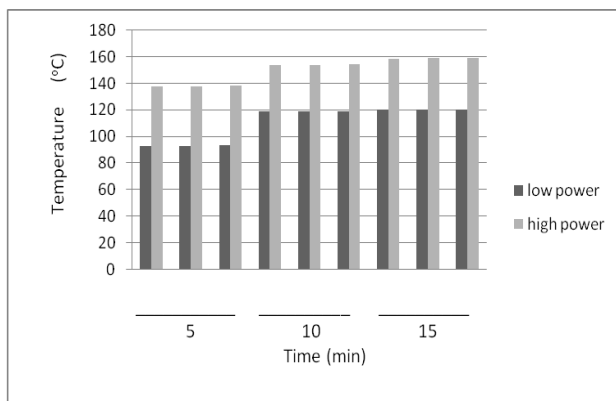


Figure 1. Variation in temperature for blend at various microwave settings

a technique for measuring the energy necessary to establish a nearly zero temperature difference between a substance and an inert reference material, as the two specimens are subjected to identical temperature regimes in an environment heated or cooled at a controlled rate. DSC has been used to describe and interpret thermal properties and chemical composition of different vegetable oil samples in terms of melting and crystallization behaviors (Tan and Che-man, 2000), to monitor oxidation processes (Tan and Che-man, 1999). Studies on crystallization and melting behavior of fats observed by DSC indicate changes in lipid composition or help characterizing products. Thermal oxidative decomposition of edible oils examined by DSC can be used for predicting oil stability. Using DSC in the freezing range has a great potential for measuring and modeling frozen food thermal properties, and to estimate the state of water in foods and food ingredients. Physicochemical and sensory evaluation is also required for product characterization.

Fats are generally blended to achieve the desired texture, taste, and melting characteristics along with the physical characteristics. Hydrogenated palm kernal oil (HPKO) and butter fat are blended and used in the chocolate industry. But, the behavior of the blended fats/oils during various processes is still unexplored. No study pertaining to the microwave heating and its effect on blended fat has so far been undertaken. Therefore, this research examined the impact of microwave heating on the different physicochemical properties and thermal behavior of blended fat.

**Materials and Methods**

Partially hydrogenated palm kernel oil (HPKO) was procured from Kamani Oils Pvt. LTD. Mumbai, India and butter were procured from the local market of Sangrur, Punjab, India. Mixture of fatty acids of methyl esters was obtained from Sigma Aldrich, USA. All chemicals used in experiments were of analytical grade.

*Preparation and selection of blend*

HPKO (Hydrogenated palm kernel oil) is generally used in many chocolate confectionaries for its high melting point (32°C) and high lauric acid content (48.2%). Two blends in the proportions of 3:1, 3:2 were prepared from completely hydrogenated palm kernel oil and salted butter respectively in molten state. These fats are generally used by confectionary industry, therefore were selected as per the industrial requirements. Whereas ratio of fats were selected on the basis of melting point and emulsion ability. Blends were prepared by Dualit, 250 watt immersion hand blender with a velocity of

Table 2. Variations in fatty acids of blend at undre
different microwave conditions

| Micowave power | Time (min) | Fatty acids (%) | | |
|---|---|---|---|---|
| | | Saturated (SFA) | Mono Unsaturated (MUFA) | Polly unsaturated (PUFA) |
| Low | 5 | 75.8 | 22.4 | 1.8 |
| | 10 | 75.8 | 22.4 | 1.8 |
| | 15 | 76.0 | 22.3 | 1.79 |
| High | 5 | 76.6 | 21.8 | 1.77 |
| | 10 | 78.29 | 20.9 | 1.73 |
| | 15 | 80.01 | 19.4 | 1.68 |

500 rpm at temperature 27±2°C. The prepared blends were kept at room temperature (25±2°C) for one hour and were analyzed for their melting points (MP of 3:2 blend- 34.3°C: MP of 3:1 blend- 31.2°C). On the basis of the higher melting point and better sensory evaluated emulsion, the blend in the proportions of 3:2 was selected for the further study.

*Microwave treatment*

A domestic microwave oven (Model: Positron, IFB Industries Ltd., India), was used. Forty grams of blend was heated for 5, 10 and 15 min at each low and high power settings. Between tests, the oven doors were opened and a fan was used to blow ambient air to facilitate cooling procedure. The temperature of oven was reduced to 30°C before each microwave treatment, so that the rise in temperature in blend after microwave treatment can be noted without any errors. The temperature of the treated blends immediately after exposure of each time period was determined with a thermometer. The change in temperature is graphically represented in Figure 1. When the sample was treated at low power setting of microwave for 5 min, the measured temperature of the sample was 93°C which increased to 159°C after a heat treatment of 15 min at high power settings. The microwave treated blend was stored under nitrogen at -18°C so as to retain the physico-chemical changes in blend after microwave treatment. Analysis of blend was carried out immediately after heating experiments.

*Physico-chemical and sensory analysis*

The AOCS Official Methods were employed for determinations of Free fatty acids (FFA) [Ca 5a-40], Peroxide value (PV) [Cd 8-53], Iodine value (IV) [Cd 1-25], in the blended fat (AOCS, 2004). Color of the oil samples was determined by Tintometer (Model F, Effem Technologies Pvt. Ltd, New Delhi, India). Fatty acids of triglycerides were analyzed by preparing methyl esters according to a conventional procedure consisting of saponification followed

by acidification and finally methylation using diazomethane as per the reported method (Sharma *et al.*, 2006). Gas chromatographic (GC) analysis of fatty acid methyl esters was carried out using a NUCON SERIES 5700 of data station 0-2.5 mV range and < 1.5s response rate. A 2m x 2 mm stainless steel 10% Silar 7C column packed with 60-120 mesh Gas Chrom Q was used. The injector and detector temperatures were maintained at 240°C. The column temperature was set at 160°C for 5 min and then ramped at a rate of 5°C per min to a final temperature of 220°C and kept there for 20 min. The total time for analysis was 37 min. Fatty acids were tentatively identified by comparison with retention times of authentic reference samples and the quantification was made based on the percentage area. The ratios of C18:2/C16:0 were then calculated.

*Sensory parameters*

The blended samples were evaluated for sensory parameters in the form of appearance and formed emulsion ability by ranking method (Ranganna, 1991). Six trained panelists ranked the coded samples according to the specified characteristics (color and texture). There were two samples per test, the rank sum for the samples were 9 and 10. The sample with rank sum 10 was found significantly superior at1% level and was selected for the study.

*DSC analysis*

Differential scanning calorimeter (Mettler Toledo STAR e SW 9.00) was used for thermal analysis of blended samples. Purified nitrogen (99.999% purity) was the purge gas for the dry box and flowed at 20 ml/min. Samples, 4 mg were weighed into aluminum pans and covers were hermetically sealed into place. An empty, hermetically sealed aluminum pan was used as reference. Prior to analysis of samples, the baseline was obtained with an empty, hermetically sealed aluminum pan. Samples were subjected to the following temperature program: Sample was melted at 50°C and held for 5 min before cooling to −50°C at the rate of 5°C/min. The cooling curves of the samples showed two distinct crystallization peaks A, and B. The percentage areas of these peaks were calculated with the 7 Series/UNIX DSC software.

*Statistical analysis*

Each value is the mean of three repetitions. Standard deviation was applied by using Microsoft excel software. All experimental data was analyzed using Sigma stat software 3.5 version, to correlate the influence of microwave heating and cooling profile of sample. The DSC curve parameters and resultant

Table 3. Variation in physico-chemical parameters under different microwave conditions

| Microwave power | Heating time [min] | Peroxide valur [meq $O_2$/kg lipids] | Iodine value | Free fatty acids [%] | Color value [Units] | C18:2/ C16:0 |
|---|---|---|---|---|---|---|
| Low | 5 | $0.571\pm0.00^{a,b}$ | $14\pm0.1^{a}$ | $0.018\pm0.00^{c}$ | $7\pm1^{a}$ | $0.13\pm0.0^{a}$ |
| | 10 | $0.573\pm0.02^{a}$ | $13.88\pm0.1^{a}$ | $0.018\pm0.01^{c}$ | $7.5\pm0^{b,c}$ | $0.128\pm0.0^{c}$ |
| | 15 | $0.586\pm0.00^{b}$ | $13.86\pm0.0^{a,c}$ | $0.019\pm0.001^{b,c}$ | $8\pm0^{c}$ | $0.121\pm0.01^{c}$ |
| High | 5 | $0.603\pm0.00^{a}$ | $13.00\pm0.1^{b}$ | $0.019\pm0.002^{c}$ | $8\pm1^{a}$ | $0.11\pm0.00^{a}$ |
| | 10 | $0.662\pm0.02^{bc}$ | $12.56\pm0.2^{a}$ | $0.02\pm0.00^{bc}$ | $8.5\pm0^{ac}$ | $0.11\pm0.01^{ac}$ |
| | 15 | $0.717\pm0.02^{c}$ | $11.23\pm0.1^{c}$ | $0.021\pm0.01^{a}$ | $12.5\pm1^{b}$ | $0.102\pm0.00^{c}$ |

[a-c] Means within same column with different superscripts are significantly different ($P<0.05$)

parameters from standard chemical method analysis were located in the mentioned software using Pearson's correlation analysis method and results were highlighted with significant differences ($P < 0.05$).

## Results and Discussion

*Physico-chemical characterization of blend*

Two blends consisting of HPKO and butter in the proportions of 3:1 and 3:2 were prepared. HPKO contained 92.5% saturated, 4.1 % MUFA (monounsaturated fatty acids) and 2% PUFA (polyunsaturated fatty acids) whereas butter had nearly 59.4% saturated, 40% MUFA, and 0.6% PUFA. The proximate composition of butter was 80.2% fat, 16.3% moisture, 2.5% salt and 1% curd. The prepared blended fat samples in the ratio of 3:2 and 3:1 had melting points, 34.3°C and 31.2°C respectively. Butter in combination with HPKO provides glace, flavour, and soft body to the emulsion. Phosphatides (lecithin) are present in butter and are therefore considered to impart better emulsification in confectionery formulations, compared with vegetable fats (Minife, 1989). On the basis of the higher melting point and better sensory parameters, the blend in the proportions of 3:2 was selected for the further use in study.

The initial characteristic of blended fat (control), HPKO and Butter, in the ratio of 3:2, is shown in Table 1. The blended fat was characterized for PV, IV, FFA, Color values and fatty acid composition. The blended fat contained in the ratio of 3:2 showed an appreciable amount of lauric (24.1%), oleic (22.4%) palmitic (13.5%), and stearic acid (13.0%). HPKO contained high amount of lauric and palmitic acids i.e. 48.2% and 15.4% respectively whereas the butter had high amount of palmitic 30.0% and oleic acids 40.0%. The composition of lauric and palmitic acid in the HPKO is reported as 49.9% and 9.9% respectively (Williams *et al*., 1997). Linoleic and palmitic acids are usually used as indicators of the extent of fat deterioration because linoleic acid is more susceptible to oxidation where as palmitic acid is more stable towards oxidation. The ratio of linoleic and palmitic acid (C18:2/C16:0) was found 0.13 for control sample as represented in Table 1. The PV, IV, and FFA in HPKO were found 0.46 meqO$_2$ / kg lipids, 6.8, and 0.002% respectively. The composition of palmitic and oleic acid in milk fat/butter is reported as 25-29% and 30-40% respectively (Bylund, 1995). The PV, IV, and FFA for butter were found 0.65meqO$_2$/kg lipids, 0.06 and 0.63% respectively.

The data in Table 2 reflect the compositional changes in the saturated, monounsaturated, and polyunsaturated fatty acids. At low power, no significant difference was observed. After 15 min of microwave heat treatment at high power setting, polyunsaturated and monounsaturated fatty acids decreased from 1.8 to 1.68 % and 22.4 to 19.4 % respectively. Minar *et al*. (2003) also reported the same pattern of decline in polyunsaturated fatty acids of sunflower, soyabean and peanut oil, on increasing microwave heating period.

The C18:2/C16:0 ratios decreased gradually along with the increase in power and time of microwave treatment (Table 3). The ratio was decreased from 0.13 to 0.102, when the blend was heated in microwave for 15 min at high power setting. George (1997) reported that when oil and fats are subjected to microwave heat treatment there is a decline in C18:2/C16:0 ratio due to decrease in relative percentage of unsaturated fatty acids and an increase in the relative percentage of saturated fatty acids. A gradual increase in color value of the samples was observed as the power of microwave increases. The visual changes were also evident in the blended fat as can be seen in Figure 2. The microwave treated blend showed maximum color value, 12.5 units as compared to the color value, 7 units of control sample.

Table 4. Differential Scanning Calorimetry (DSC) parameters for 3:2 blended fat

| Microwave power | Heating Time [min] | Turn on temp. [°C] | Turn off temp. [°C] | Enthalpy [J/g] | Peak height [mW] | Peak area [%] |
|---|---|---|---|---|---|---|
| | | | **Peak A** | | | |
| Low | 5 | 26.28 | 20.75 | -23.28 | 0.40 | 24.86 |
| | 10 | 26.18 | 20.28 | -20.87 | 0.42 | 25.00 |
| | 15 | 26.16 | 20.25 | -18.59 | 0.48 | 25.55 |
| High | 5 | 26.39 | 21.95 | -29.45 | 0.56 | 28.07 |
| | 10 | 26.33 | 22.69 | -20.15 | 0.73 | 28.83 |
| | 15 | 26.23 | 21.23 | -17.80 | 0.65 | 30.66 |
| | | | **Peak B** | | | |
| Low | 5 | 15.19 | 6.15 | -104.77 | 2.09 | 53.00 |
| | 10 | 12.19 | 6.12 | -98.53 | 2.14 | 53.58 |
| | 15 | 10.20 | 6.05 | -95.32 | 2.32 | 53.86 |
| High | 5 | 15.82 | 8.39 | -104.17 | 2.48 | 57.49 |
| | 10 | 15.56 | 6.52 | -92.85 | 2.70 | 58.99 |
| | 15 | 15.48 | 6.29 | -78.07 | 3.16 | 61.07 |
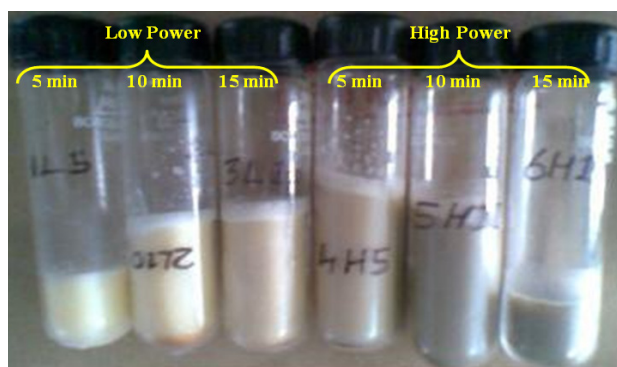


Figure 2. Color changes in blended fat after microwave heat treatment

FFA contributes to the development of off-flavors in the oils and fats. The FFA value for control sample was found 0.018%. The free fatty acid value increased with the increase in microwave power settings and time. The percent free fatty acids was 0.021% when the samples were exposed to high power treatment for 15 min. Tan *et al.* (2001) reported the same trend in fatty acids when corn oil and soybean oil were exposed to microwave heat treatment.

Iodine value (IV) gradually decreased with the increased heating power settings and time (Table 3). IV for the control sample was 14, which remains unchanged when sample was exposed to low power microwave treatment for 5 min thereafter, IV was decreased. The percentage reduction in IV for low and high power treatment for 15 min was 1% and 19.7% respectively. The reduction in IV during heating is often taken as a measure of fat deterioration (Fritsch, 1981). The IV, 11.23 in the blended fat samples, treated at high power setting for 15 minutes indicates enhanced changes in the degree of unsaturation. The similar pattern of increase in saturated fats and decrease in IV was reported by Caponio *et al.* (2002). Microwave heating reported the formation of polar compounds after microwave heat treatment in olive oil which ultimately results in decreased iodine value. On increasing the microwave power and time setting, the FFA was found increasing while IV for the blended fat was decreasing. Therefore FFA% and IV for the blended fat were found to be significant and indirectly correlated.

Peroxide value of control sample was initially $0.531 meqO_2$ / kg lipids. At high power setting for 15 min the PV increased to $0.717 meqO_2$ / kg lipids, while at lower power setting for 15 min PV was found $0.586 meqO_2$ / kg lipids (Table 3). The similar trend of PV after raising heating time and temperature has been reported by Vieira and Regitano-D'Arce (2001) for the canola oil thermal oxidation. The value of PV for fats and edible oils is susceptible until it reaches $10 meqO_2$ / kg lipids (PFA, 1954). The maximum PV reached up to $0.717 meqO_2$ / kg lipids (Table 3) at high power setting for 15 min. The changes in PV were significant at high power settings but did not reflect the deterioration in the samples. The changes in peroxide value may be due to the amount of oxygen that must be absorbed or peroxides that must be formed to produce noticeable oxidative rancidity in fats/oils varying with their composition.

Blended fat to be used in confectionary should have a specific melting point, so that it can be incorporated in manufacturing of confectionary items, which are generally stored at low temeprature condition/room temperatures. The microwave treated blends exposed to DSC reflected two kinds of peaks i.e. exothermic (when sample is treated at low temperature) and endothermic (when sample is treated at high temperature). The blend, used in confectionery is known for its characteristics feature, it was found essential to identify its thermo gram on low temperatures. Therefore, exothermic peaks were

Table 5. Pearson correlation coefficient amongst analytical and DSC parameters

| Chemical Parameters | High power Peak A | Peak B | Low power Peak A | Peak B | DSC parameters |
|---|---|---|---|---|---|
| Heating time | -0.719* | -0.825* | -0.834* | -0.802* | |
| Peroxide value | -0.803 | -0.745 | -0.886 | -0.972 | |
| Iodine value | 0.813* | 0.756* | 0.921* | 0.814* | Turn on temp. |
| Free fatty acid | -0.619* | -0.825* | -0.936* | -0.993* | |
| Colour | -0.886 | -0.941* | -0.734 | -0.802 | |
| C18:2/C16:0 | 0.929* | 0.921* | 0.840* | 0.946* | |
| Heating time | -0.931* | -0.998* | -0.875* | -0.832* | |
| Peroxide value | -0.911 | -0.820 | -0.917 | -0.965 | |
| Iodine value | 0.931* | -0.829* | -0.993* | -0.900* | Turn off temp. |
| Free fatty acid | -0.893* | -0.998* | -0.816* | -0.831* | |
| Colour | -0.935* | -0.917* | -0.875 | -0.932 | |
| C18:2/C16:0 | 0.891* | 0.911* | 0.885* | 0.977* | |
| Heating time | -0.855* | -0.997* | -0.812* | -0.990* | |
| Peroxide value | -0.868* | -0.995* | -0.872* | -0.860* | |
| Iodine value | 0.942* | 0.879* | 0.965* | 0.811* | Enthalpy |
| Free fatty acid | -0.855* | -0.986* | -0.926* | -0.823* | |
| Colour | -0.820* | -0.941* | -0.912 | -0.890 | |
| C18:2/C16:0 | 0.926* | 0.902* | 0.824* | 0.897* | |
| Heating time | 0.829* | 0.917* | -0.856 | -0.951 | |
| Peroxide value | 0.996 | 0.936 | -0.942 | -0.854 | |
| Iodine value | -0.972* | -0.890* | 0.920* | -0.997* | Peak Height |
| Free fatty acid | 0.929 | 0.895 | 0.959 | -0.868 | |
| Colour | 0.835 | -0.993* | -0.956 | -0.951* | |
| C18:2/C16:0 | -0.965* | -0.982* | -0.954 | -0.910 | |
| Heating time | 0.972* | 0.995* | 0.945 | 0.980 | |
| Peroxide value | 0.911 | 0.959 | 0.992 | 0.917 | |
| Iodine value | -0.999* | -0.972* | -0.995* | -0.982* | Peak area |
| Free fatty acid | 0.941* | 0.934* | 0.942* | 0.940* | |
| Colour | 0.982 | 0.946* | 0.945 | 0.980* | |
| C18:2/C16:0 | -0.977* | -0.968* | -0.977 | -0.969 | |

* significance at 0.05 level (P < 0.05).

only considered for further study. Table 4 reflects the Turn on temperature (Ton), Turn off temperature (Toff), enthalpy, peak height and peak area of peak A and B. The Trange (temperature range) of crystallization in cooling profile of blended fat was nearly 26 to 6°C. On increasing the time and power of microwave settings from 5 to 15 min and low to high power, saturated fatty acids were increased, which resulted in the decrease of turn on (Ton) temperature of crystallization. At low power settings the turn on temperature after 5 min of heating for peak A was found 26.28°C, which was decreased to 26.16°C after 15 min of microwave heat treatment. Similarly turn on temperature was decreased from 26.39°C to 26.23°C when the sample was heated for 5 to 15 min at high power settings. The data in Table 4 depicted the decrease in Toff (turn off temperature) from 20.75°C to 20.25°C and from 6.15 to 6.05°C for Peak A and B respectively as the time of heat treatment increased at a low power setting. At high power setting, as the heating time increased there was an decrease in Toff from 21.95 to 21.23°C and 8.39 to 6.29°C for peak A and B respectively. Since phase transition of sample involves breaking and formation of bonds, energy will be released or taken up when such events occur, enabling it to be detected. For detecting the temperature release during each

exothermic peak appearance, enthalpy for each peak was evaluated. It is evident from Table 4 that for peak A there was a decline in enthalpy from -23.28 to -18.59 J/g and -29.45 to -17.80 J/g at low and high power settings respectively. For Peak B there was a decrease in enthalpy at low and high power settings from -104.77 to -95.32J/g and -104.17 to -78.07 J/g respectively as microwave heating treatment time was raised from 5 to 15 min. This may be due to the increase in saturated fat content from the increase in microwave heating time and change of power setting. More the saturated fat less heat will be evolved during crystallization. Therefore, the amount of heat release decreased as the microwave heat treatment time was increased during crystallization of sample for each exothermic peak (Table 4). As the microwave treatment time increased at a fixed power setting, the temperature for complete crystallization was decreased as represented by first peak (A) and second peak (B) (Figure 3 and 4). This may be due to the increase in saturated fat as the microwave treatment time and power increased, which caused reduction in the crystallization temperature of blended fat. Chiavaro et al. (2009) found changes in DSC cooling profiles for extra virgin olive oil and olive–pomace oil subjected to microwaving, with the major exotherm that shifted towards lower temperature. Peak height
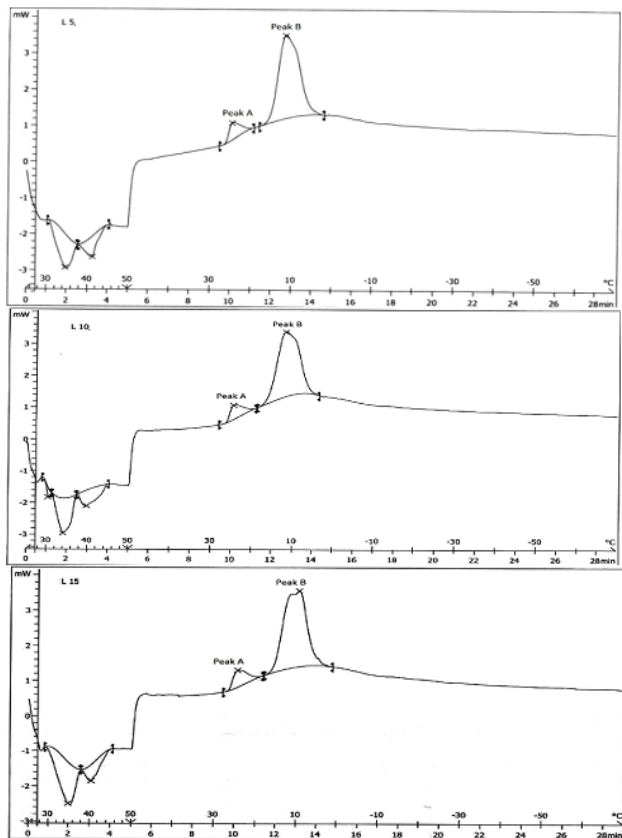
Figure 3. Cooling profile of blends heated in microwave for 5, 10, and 15 min at low power setting (L5, L10, L15). mW –megawatt, Peak A-first endothermic peak, Peak B-second endothermic peak
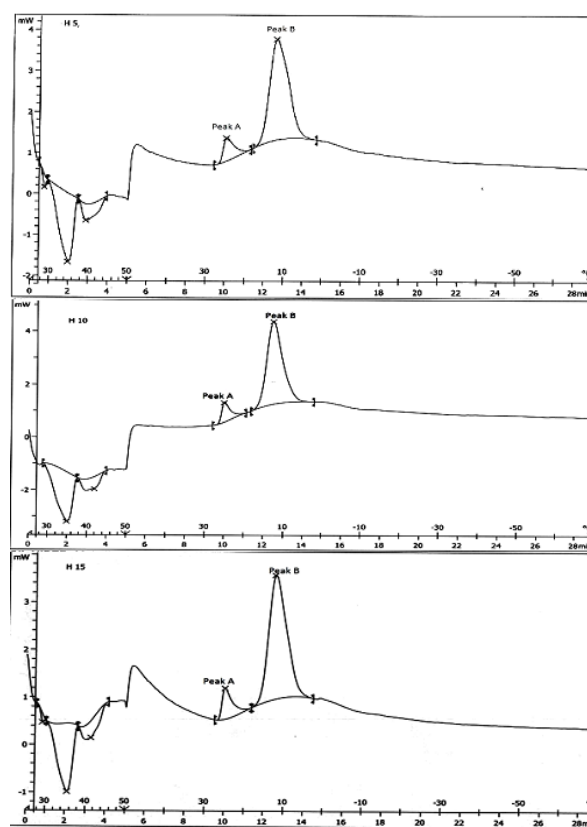


Figure 4. Cooling profile of blends heated in microwave for 5, 10, and 15 min at high power setting (H5, H10, H15). mW –megawatt, Peak A-first endothermic peak, Peak B-second endothermic peak

for each peak was found increasing as the microwave heat treatment time and power setting was increased from 5 to 15 min and low to high power settings respectively.

The percentage area of the peak increased with the increase in microwave treatment time and power (Table 4). The high value of peak areas in DSC curves reflects the high amount of energy is expelled to achieve low temperatures. The increase in area was maximum, 30.66% (peak A) and 61.07% for (peak B), for the blended fat, treated at high power for 15 minutes. This may be due to decrease in unsaturated triacylglycerols (TAG) and the formation of more saturated TAG due to which the crystallization temperature is achieved after expelling high amount of energy. Tan and Che-man (2000) observed the similar trend in corn and soybean oil, treated at high microwave power settings.

The matrix of correlation coefficient between analytical parameters and DSC curve parameters is shown in Table 5. Correlation coefficient was found between Ton, Toff, enthalpy, peak height, peak areas and between several chemical parameters focusing the significant difference between them. Ton of DSC for each peak showed a negative and

significant correlation with heating time, FFA and color, whereas it reflected a negative and insignificant correlation with PV, IV and C18:2/C16:0 were also found to be decreasing with increase in heating time and microwave power setting, hence the correlation of Ton with IV and C18:2/C16:0 was found positive and significant for both the peaks. Toff for each peak of DSC thermogram showed a gradual decrease as the microwave treatment time and power setting was increased. Therefore Toff for each peak found to have a negative and significant correlation with heating time, FFA and color (Table 5), whereas it showed a positive and significant correlation with IV and C18:2/C16:0 ratio, due to the gradual decline in C18:2/C16:0 and IV with decrease in Toff for each peak. For both peaks, the Toff and PV showed a negative and insignificant correlation. Due to decline in enthalpy at each peak on increasing the power and time settings, enthalpy for each peak showed a positive and significant correlation with IV and C18:2/C16:0 and a negative and significant correlation with heating time and FFA. Enthalpy for both the peaks showed a significant and negative correlation with color only at high power settings. At low power settings the correlation between enthalpy of both the

peaks and color was found negative and insignificant. DSC peak areas A and B revealed good correlations with different heating periods at high power settings whereas it shows poor correlations at lower power settings (Table 5). Tan *et al.* (2001) also examined the similar trend while studying the correlation among peak areas developed after microwave heat treatment of corn and soya bean oil. PV at low and high power settings, with peak area of peak A and B showed direct correlations with coefficients values 0.992 and 0.917 and 911 and 0.959 respectively. However, these were found to be non-significant (P>0.05) (Table 5). This may be attributed to rapid decomposition of hydroxyperoxides to secondary oxidation products at high power and temperature settings (Tan *et al.*, 2001). Iodine value reflected a negative and significant correlation coefficient of -0.995 and -0.982 with peak area, A and B obtained at low power settings and-0.999 and -0.972 at high power settings respectively (Table 5). The negative correlation among these two parameters indicated that the peak area value of the blended fat is inversely related with the iodine value of that blend. FFA content and peak areas also showed a positive and significant correlation (P<0.05) (Table 5). The correlation coefficient was greater than 0.9 in all the cases of microwave treatment. The increase in microwave treatment time and power revealed a trend of darkening the color in the blended fat, which is clearly visible in the Figure 2. There is positive and significant correlation (P<0.05) of color with the peak areas B of the samples exposed to the low and high power settings whereas the correlation was found to be positive and non-significant (P>0.05) for the peak areas A of blended samples exposed at both the power settings (Table 5). The ratio of linoleic to palmitic acid (C18:2/C16:0) revealed negative and significant correlation only at high power settings. DSC Peak height for both peaks showed similar pattern of correlation among chemical parameters like peak area.

## Conclusion

The blended fat constituting HPKO and butter in the proportion of 3:2 was found better in terms of appearance and emulsion. The increase in microwave treatment time and power resulted in increase in fat/oil oxidation which is indicated by 16.6% increase in FFA, 25.56% increase in PV, 21.5% decrease in C18:2/C16:0 ratio and 19.27% decrease in IV. Color value showed 78.5% increase when the blended fat was treated for 15 min at high power setting. The microwave treated blended fat revealed two exothermic peaks while studying its thermal behavior. The Ton (turn on temperature), Toff (turn off) and enthalpy for each DSC peak was found decreasing whereas, peak height and peak areas of each peak were found increasing on rising the microwave heat treatment time and power settings. The DSC curve parameters revealed 24.3% and 13.21% increase in peak "A" and peak "B" area respectively when the blended fat was treated for 15 min at high power. The DSC peak areas and peak height for A and B showed significant correlations with physicochemical parameters like IV and FFA at both high and low power settings whereas significant correlations with heating periods and C18:2/C16:0 were observed at high power settings. Color value revealed significant correlation only with area and height of peak B. The trend of increase and decrease in FFA and IV respectively, and their significant correlation with Ton, Toff, Enthalpy peak height and areas of peak A and B revealed that these DSC curve parameters can also be recommended as an appropriate objective method for estimating the extent of fat deterioration during microwave heating. Further studies can be undertaken to utilize blended fats in various formulations using microwave heating operations.

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