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Enhancement of the oxidative stability of some vegetable oils by blending with *Moringa oleifera* oil

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Abstract

Blends (20%, 40%, 60%, 80% w/w) of *Moringa oleifera* oil (MOO) with sunflower oil (SFO) and soybean oil (SBO) were prepared to evaluate the changes in fatty acid (FA) composition, oxidative and thermal stability of SFO and SBO. The blending of MOO with SFO and SBO in proportions of 0–80% resulted in the reduction of linoleic acid ($C_{18:2}$) content of SFO and SBO from 67.0% to 17.2% and 56.2% to 14.6% and increase in the contents of oleic acid ($C_{18:1}$) from 26.2% to 68.3% and 21.4% to 65.9%, factors of 0.72, 0.72 and 1.27, 1.33, respectively. A storage ability test (180 days; ambient conditions) showed an appreciable improvement in the oxidative stability of substrate oils with increase of MOO concentration, as depicted by the least oxidative alterations in PV, IV and highest increase in induction period, IP, of the MOO:SBO (80: 20 w/w) blend. Each 20% addition of MOO resulted in decreases of PV and IV by factors of 0.84, 0.85 and 0.89, 0.88, respectively, and increases in IP by factors of 1.45 and 1.37 of SFO and SBO, respectively.

The heating performance test (180 °C for 42 h; 6 h heating cycle per day), as followed by the measurement of polymer contents and total polar contents (TPC), also revealed the MOO:SBO (80:20 w/w) blend to be the most stable. Every 20% addition of MOO in SFO and SBO resulted in reduction of the polymer contents and TPC of SFO and SBO by factors of 0.91, 0.92 and 0.94, 0.94, respectively. On the basis of the present findings, it appears that proper blending of high linoleic oils with MOO can result in oil blends which could meet nutritional needs with improved stability for domestic cooking and deep-frying.

Keywords: Blending; Storage stability; Heating performance; *Moringa oleifera* oil; Fatty acid composition; Total polar components; Induction period

1. Introduction

During storage and heat treatment, vegetable oils undergo hydrolysis, oxidation and polymerization, resulting in quality deterioration with respect to their sensory and nutritive value. Although the mechanisms of such processes are essentially the same in different fats, the kinetics of deteriorative reactions may vary (Che Man, Liu, Jamilah, & Rahman, 1999). The deep fried flavours are due to degradation products of linoleic acid (Pokorny, 1989) and their intensity can be lowered if the food is fried in oil of low linoleic acid content. Nutritional advantages have been recognized for oils rich in oleic and other mono-unsaturated fatty acids with reduced linoleic acid contents and low contents of saturates (Nestel, Clifton, & Noakes, 1994).

Recent studies have demonstrated that diets with high contents of oleic acid are associated with low levels of low-density lipoprotein cholesterol in blood plasma and they may reduce the incidence of coronary heart diseases (Noakes, Nestel, & Clifton, 1996).

Oleic acid ($C_{18:1}$) is the most abundant mono-unsaturated fatty acid in many common edible oils, e.g. canola oil. Compared with polyunsaturated fatty acids, oleic acid is more resistant toward oxidation, both at ambient storage

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and at high temperatures (Warner & Knowlton, 1997) that prevail during the cooking and frying of food. Conventionally, soybean, rapeseed, sunflower or peanut oils, with high contents of polyenoic FA, are the main edible oils used for domestic cooking purposes (Erickson, 1996). Pan-frying, however, is not suitable for deep fat frying due to the higher magnitude of thermoxidation at elevated temperatures. Some low-linoleic, high-oleic vegetable oils could be used for deep-frying, e.g. canola, olive, or almond oils, as they are quite stable at high frying temperatures. However, their high cost restricts their usage on a major scale.

Therefore, the use of more stable frying oils of comparatively low price would be desirable. To overcome the problem of poor stability of traditional soybean, sunflower and rapeseed oils, ways of reducing the unstable polyunsaturated fatty acid content were sought. One way to improve the stability of these oils is by blending with oils of high-oleic acid contents. Blending of vegetable oils and fats has emerged as an economical way of modifying the physicochemical characteristics of vegetable oils and fats besides enhancement in oxidative stability (Chu & Kung, 1997, 1998; Premavalla, Madhura, & Arya, 1998).

Proper mixing of high-oleic and high-linoleic oils may result in oil blends with improved stability characteristics. Mariod, Matthaus, Eichner, and Hussain (2005) investigated improvement in the oxidative stability of sunflower kernel oil by blending with non-conventional Sudanese oils. Studies of Padmavathy, Siddhu, and Sundararaj (2001) have shown that the FA profile of the oils can be improved by blending; hence, the need to hydrogenate unsaturated oils is appreciably decreased, thereby eliminating the chances of formation of harmful *trans*-FA. Gupta, Sinddhu, and Sundararaj (2001) studied the oxidative stability of edible grade crude palm oil (CPO) blends with sunflower oil or ground nut oil (GNO) as the deep-frying medium and reported that CPO:SFO had better oxidative stability than had CPO:GNO.

Moringa oleifera Lam. is the most widely known and utilized species, belonging to the family Moringaceae. A native of the sub-Himalayan regions of northwest India, *M. oleifera* is also indigenous to many countries in Africa, Arabia, Southeast Asia, the Pacific, Caribbean islands and South America (Siddhuraju & Becker, 2003). As a traditionally important food commodity, *M. oleifera* has received attention as ''natural nutrition of the tropics''. The leaves, flowers, fruits and roots of this multipurpose tree are locally esteemed as a vegetable (Anwar & Bhanger, 2003). In addition to its myriad uses and superior nutritional benefits, *M. oleifera* also has surprising medicinal attributes and is used in the treatment of ascites, rheumatism, venomous bites, and as a cardiac and circulatory stimulant (Anwar, Ashraf, & Bhanger, 2005). The plant has been well positioned in Ayurvedic, Unani, and even allopathic systems of medicine (Mughal, Ali, Srivastava, & Iqbal, 1999). *M. oleifera* seeds and the extracted oil, known commercially as ''ben oil'' or ''behen oil'', have been extensively used in the enfleurage process. Oliveira and Silveira (1999) described the composition and nutritional attributes of *M. oleifera* seeds and suggested that these antipyretic, acrid, and bitter seeds could be utilized for wastewater treatment (Ndasbigengeser & Narasiah, 1998). Numbers of studies have been conducted on the characterization of *M. oleifera* oil (MOO) (Anwar et al., 2005; Abdulkarim, Long, Lai, Muhammad, & Ghazali, 2005; Tsaknis & Lalas, 2002). The MOO is reported to have a high level of oleic acid and different tocopherol isomers (Anwar et al., 2005). Tsaknis and Lalas (2002) reported that MOO has excellent oxidative stability during frying. So, great potential exists for blending of MOO with other high-linoleic oils.

As food habits of most of the Pakistani population are based on deep fried/baked foods, oxidative-resistant oils are needed. Conventionally available cooking oils can not fulfil this requirement; rather, they may cause serious health disorders due to the generation of hazardous oxidation products. This requirement can be conveniently met through the blending process. In the present study, efforts have been made to investigate the effects of blending of MOO on the oxidative stability of high-linoleic oils. No such previous studies have yet been conducted on the blending of MOO. This report might serve as a milestone toward development of newer blended oils with improved stability characteristics.

2. Materials and methods

2.1. Samples and standards

The seeds of *M. oleifera* were collected from the periphery of the University of Sindh, Jamshoro, Pakistan, whereas, the seeds of sunflower and soybean were obtained from the Agricultural Research Institute, Tandojam, Pakistan. All reagents used were from E. Merck or Sigma Aldrich unless stated otherwise. Pure standards of fatty acid methyl esters were obtained from Sigma Chemical Co. (St. Louis, MO).

2.2. Extraction of vegetable oils

The seeds were dehulled, crushed and ground to pass through a 0.5 mm sieve by a grinding mill (Petra electric, Burgau, Germany). The crushed seeds (200 g) were then fed into a Soxhlet extractor fitted with a 1 l round-bottom flask and a condenser. The extraction was executed on a water bath for 4–5 h with 0.5 l of *n*-hexane. The solvent was distilled off under vacuum in a rotary evaporator (EYELA, Rotary Vacuum Evaporator, N.N. Series, equipped with an Aspirator and a Digital Water Bath SB-651, Japan).

2.3. Degumming of oils

The oils to be degummed were heated at 70 °C on a water bath. Hot water was added to a final volume of 18%, and

mixed for 10 min with the aid of a glass rod. After cooling, the oils were centrifuged (3000 rpm i.e. 1221*g*) for 10 min in tubes (100 cm^3) in an automatic refrigerated centrifuge (CHM-17; Kokusan Denki, Tokyo, Japan) (Anwar et al., 2005). The degummed and centrifuged oil was left in contact (stirred) with anhydrous sodium sulfate for ca. 5 min, filtered through a filter paper by gravity in a vacuum drying oven (EYELA, VOC-300 SD, Tokyo, Japan) at 50 °C and stored in separate sealed bottles under refrigeration (0–4 °C) until used for blending purposes.

2.4. Blending of vegetable oils

The vegetable oil blends were formulated by blending MOO with preheated (50 °C) sunflower oil (SFO) and soybean oil (SBO) in proportions of 80:20, 60:40, 40:60, and 20:80% (w/w). The oils were thoroughly mixed to form uniform blends. Quality evaluation of the oil blends was done by employing storage ability and thermal stability tests.

2.5. Storage ability test

Pure oils and blended oil formulations were stored under ambient conditions for a period of 180 days. The level of oxidative deterioration was assessed periodically, every month, following the measurement of PV, IV and IP.

2.6. Analysis of pure and blended oils

2.6.1. Determination of PV and IV

Determinations of peroxide value (PV) and iodine value (IV) of the pure and blended oils were carried out, following AOCS official methods cd 8–53 and cd 1–25, respectively (AOCS, 1997).

2.6.2. Oxidative stability

An automated Metrohm Rancimat apparatus, model 679, capable of operating over a temperature range of 50–200 °C, was used to determine induction periods (IP) of the pure and blended oils (Metrohm, 1993). Testing was carried out at 120 ± 0.1 °C, and oxidative stability was measured, following the procedure described elsewhere (Anwar, Bhanger, & Kazi, 2003). Briefly, oil (2.5 g) was carefully weighed into each of the six reaction vessels and analyzed simultaneously. IPs of the sample were recorded automatically and corresponded to the break point in the plotted curves.

2.6.3. Fatty acids composition

Fatty acid methyl esters (FAMEs) were prepared according to the standard IUPAC method (1987) 2.301 and analyzed on a SHIMADZU gas chromatograph model 17-A, fitted with a methyl lignoserate-coated (film thickness 0.25 μm), SP-2330 (SUPELCO Inc. Supelco Park Bellefonte, PA 16823-0048, USA) polar capillary column (30 m × 0.32 mm), and a flame ionization detector. Oxygen-free nitrogen was used as a carrier gas at a flow rate of 5.0 ml min^{-1}. Other conditions were as follows: initial oven temperature, 180 °C; ramp rate, 5 °C min^{-1}; final temperature, 220 °C; injector temperature, 230 °C; detector temperature, 250 °C; temperature hold, 2 min before the run and 10 min after the run. A sample volume of 1.5 μl was injected. FAMEs were identified by comparing their relative and absolute retention times to those of authentic standards. A data-handling programme, Chromatography Station for Windows (CSW32) was used for the quantification. The fatty acid composition was reported as a relative percentage of the total peak area.

2.7. Thermal stability test

2.7.1. General

In this evaluation, blended and pure oils were heated at 180 °C in a fryer for 42 h (6 h heating cycles each day) for a period of 7 days. Samples of blended and pure oils were taken for every 6 h heating cycle and stored in a refrigerator until used for analyses. The thermoxidative degradation level was assessed by the measurement of changes in total polymer contents and total polar components (TPC). Determination of polymerized oxidized products (total polymer contents) was done according to the method of the AOAC (1984).

2.7.2. Determination of total polar components

Total polar components (TPC) were determined by means of column chromatography, following the methods of Dobarganes and Perea-Camini (1991) and AOAC (1984) with slight modification as described below.

2.7.3. Preparation of chromatography column

A chromatographic column (2.1 cm i.d. × 45 cm) made of glass, with Teflon stopper and ground glass joint was connected to the adapter. Twenty five grams of silica gel, deactivated with 8% water, were weighed into a beaker and mixed with 65 ml of hexane:ether (90:10 v/v) solvent mixture. The slurry was transferred to the column through a funnel; the stopcock was opened and solvent allowed to stay at a level of 10 cm above the silica gel. Five grams of analytical reagent grade sea sand were added onto the column and solvent was drained to the sand layer. Samples of oils were dissolved (2.0 g/30 ml) in hexane and then the sample aliquot transferred to the chromatographic column. First elution was achieved with 100 ml of hexane:ether (90:9 v/v) to elute the non-polar fraction, followed by elution with ether to elute the polar fractions. A final elution of the samples was achieved with methanol. Thence, percentage yields of polar and non-polar fractions were calculated gravimetrically.

2.7.4. Control of the separation by TLC

Control of the separation of polar and non-polar fractions was achieved by means of thin-layer chromatography (TLC), using 0.50 mm thick silica gel plates (20 × 20 cm) of E. Merck. A solvent mixture of *n*-hexane/ethyl ether/acetic

acid (80:20:1, v/v/v) was used as developing medium. Polar and non-polar fractions were diluted in *n*-hexane 0.25 g/10 ml (w/v) and applied as spots, using a microsyringe. Plates were placed in the developing tank and in the dark; solvent was allowed (ca. 30 min) to migrate until the solvent front reached within 1 cm of the top edge of the plate. Plates were removed, letting the solvent evaporate. After the solvent was driven off from the plates, the spots were visualized by spraying the plates with iodine vapours.

2.8. Statistical analysis

Samples of pure oils and various blends were taken in triplicate, analyzing each sample thrice ($3 \times 3 \times 1$). All the data are reported as means ($n = 3$) ± SD ($n = 3$) (Steel & Torrie, 1980). For all investigated parameters, two way analysis of variance (ANOVA) was performed, using the Minitab statistical software (version 13.20).

3. Results and discussion

Fatty acid composition of substrate oils and oil blends is presented in Table 1. The main fatty acids in the oils were oleic, linoleic and palmitic acids with 77.6%, 4.00% and 5.1% (MOO); 26.2%, 67.0% and 3.50% (SFO) and 21.4%, 56.2% and 11.3% (SBO), respectively. Due to blending of MOO, major changes were noted in the contents of $C_{18:1}$ and $C_{18:2}$ of the substrate oils. Blending of MOO at a proportion of 80% resulted in significant ($P < 0.001$) increases from 26.2% to 68.3% and 21.4% to 65.9%, in the oleic acid contents of SFO and SBO, respectively, whereas the contents of linoleic acid were significantly ($P < 0.001$) decreased from 67.0% to 17.2% and 56.2% to 14.6%, respectively. Blending of MOO also significantly ($P < 0.001$) modified the concentration of $C_{16:0}$, $C_{18:0}$, $C_{18:1}$ and $C_{18:2}$ of SFO, whereas the change in the content of $C_{18:0}$ in SBO was non-significant ($P > 0.05$).

Present analysis showed a gradual increase in the content of $C_{18:1}$ of the substrate oils as a function of increase in the proportion of MOO. It was noted that each 20% addition of MOO increased the content of $C_{18:1}$ of SFO and SBO by 10.5% and 11.1%, respectively. A reverse trend was observed in the case of $C_{18:2}$, where the content of $C_{18:2}$ decreased by 12.5% and 10.4%, respectively. When a factorial relationship was established, it became evident that, with every 20% addition of MOO, the content of $C_{18:1}$ of SFO and SBO increased by factors of 1.27 and 1.33, respectively, while $C_{18:2}$ content decreased by factors of 0.71 and 0.72, respectively. Mariod et al. (2005) reported that the blending of sunflower kernel oil with 40% *Sclerocarya birrea* oil resulted in an increase in oleic acid from 41.3% to 51.0% and decrease in linoleic acid from 46.3% to 31.2% in the mixture. Padmavathy et al. (2001) found that blending of crude palm oil with groundnut oil and SFO could result in modification of the fatty acid profile of the blends.

The results of oxidative stability, in terms of measurement of induction periods (Rancimat, 20 l h^{-1}, 120 °C) of the pure SFO and SBO and their blends with MOO during storage (6 months) at ambient (room temperature) conditions are shown in Table 2. The blending of MOO (80%) resulted in a marked increase in the induction period (IP), which is a characteristic of the oxidative stability of the oil and fats (Anwar et al., 2003), of the pure SFO and SBO from 1.12 to 5.99 h and 1.47 to 6.22 h, corresponding to increases in the oxidative stability 435% and 323%, respectively. It was noted that each 20% addition of MOO in pure SFO and SBO enhanced their IP by (on average) 56.5% and 43.4%, factors of 1.58 and 1.47, respectively.

The results of oxidative stability also revealed an overall decrease in IP of the substrate and blended oils over a 6-month storage, in a time-dependent manner. MOO registered a lower decline in IP from the initial value (0.75), while SFO distinctly showed a greater decline in IP from the initial value (1.87), thus indicating highest and lowest oxidative stability, respectively. The results of change in IP, with respect to the storage period of all substrate and blended oils, followed a linear regression, with values of R^2 in the range of 0.90–0.99. As a result of blending sun-

Table 1
Fatty acid composition of MOO, SFO, SBO, MOO:SFO and MOO:SBO at initial stage

Oils	Fatty acid composition (g 100^{-1} g of fatty acids, mean ± SD)[a]						
	$C_{16:0}$	$C_{18:0}$	$C_{18:1}$	$C_{18:2}$	$C_{18:3}$	$C_{20:0}$	$C_{22:0}$
MOO	**5.10 ± 0.20**	**4.00 ± 0.22**	**77.6 ± 0.60**	**4.05 ± 0.16**	–	**2.50 ± 0.10**	**5.70 ± 0.33**
SFO	**3.50 ± 0.12**	**2.40 ± 0.12**	**26.2 ± 0.30**	**67.0 ± 0.59**	–	–	–
SBO	**11.30 ± 0.3**	**3.95 ± 0.20**	**21.4 ± 0.40**	**56.2 ± 0.29**	**6.04 ± 0.23**	–	–
MOO:SFO (20:80)	3.75 ± 0.10	2.59 ± 0.15	35.7 ± 0.50	55.3 ± 0.48	–	–	0.92 ± 0.10
MOO:SFO (40:60)	4.00 ± 0.21	3.00 ± 0.17	46.8 ± 0.65	40.9 ± 0.71	–	0.93 ± 0.05	2.80 ± 0.13
MOO:SFO (60:40)	4.50 ± 0.20	3.35 ± 0.10	57.0 ± 0.60	30.0 ± 0.19	–	1.10 ± 0.10	2.99 ± 0.15
MOO:SFO (80:20)	4.75 ± 0.24	3.74 ± 0.20	68.3 ± 0.50	17.2 ± 0.34	–	0.90 ± 0.10	4.50 ± 0.23
MOO:SBO (20:80)	10.00± 0.4	4.00 ± 0.15	31.4 ± 0.29	46.5 ± 0.40	4.99 ± 0.18	0.35 ± 0.05	1.06 ± 0.08
MOO:SBO (40:60)	8.72 ± 0.25	3.96 ± 0.20	42.9 ± 0.50	35.8 ± 0.35	4.07 ± 0.12	0.70 ± 0.06	2.00 ± 0.10
MOO:SBO (60:40)	7.50 ± 0.32	3.98 ± 0.30	55.0 ± 0.70	25.3 ± 0.35	2.71 ± 0.15	1.40 ± 0.11	3.07 ± 0.17
MOO:SBO (80:20)	6.15 ± 0.18	4.05 ± 0.24	65.9 ± 0.47	14.6 ± 0.19	0.98 ± 0.08	1.70 ± 0.10	4.79 ± 0.19

Bold values are for the pure substrate oils.
MOO, *Moringa oleifera* oil; SFO, sunflower oil; SBO, soybean oil.
[a] Values are means ± SD of three separate determinations.

Table 2
Induction period of MOO, SFO, SBO, MOO:SFO and MOO:SBO during storage at ambient temperature (6 months)

Oils	Induction period[a] (h) storage period (months)						R^2	Decrease in IP from initial[b]	% Increase in IP[c]	Factor
	0	1	2	3	4	5	6				
MOO	**8.75 ± 0.35**	**8.70 ± 0.51**	**8.56 ± 0.40**	**8.44 ± 0.29**	**8.39 ± 0.41**	**8.32 ± 0.26**	**8.00 ± 0.25**	**0.93**	**0.75**	–	–
SFO	**2.99 ± 0.07**	**2.29 ± 0.10**	**1.99 ± 0.08**	**1.69 ± 0.07**	**1.41 ± 0.08**	**1.23 ± 0.05**	**1.12 ± 0.04**	**0.93**	**1.87**	–	–
SBO	**3.30 ± 0.12**	**3.02 ± 0.12**	**2.71 ± 0.07**	**2.33 ± 0.10**	**1.68 ± 0.09**	**1.57 ± 0.07**	**1.47 ± 0.05**	**0.96**	**1.83**	–	–
MOO:SFO (20:80)	3.75 ± 0.15	**3.23 ± 0.12**	**2.83 ± 0.13**	**2.74 ± 0.13**	**2.61 ± 0.15**	**2.23 ± 0.12**	2.02 ± 0.08	0.95	1.73	80.36	1.80
MOO:SFO (40:60)	5.72 ± 0.20	5.41 ± 0.20	5.02 ± 0.19	4.86 ± 0.18	4.56 ± 0.19	4.32 ± 0.13	4.11 ± 0.12	0.99	1.61	103.47	2.03
MOO:SFO (60:40)	6.76 ± 0.25	6.11 ± 0.22	5.96 ± 0.26	5.76 ± 0.28	5.61 ± 0.21	5.47 ± 0.25	5.33 ± 0.26	0.90	1.43	29.68	1.36
MOO:SFO (80:20)	7.29 ± 0.30	7.07 ± 0.36	6.53 ± 0.33	6.48 ± 0.34	6.41 ± 0.31	6.32 ± 0.38	5.99 ± 0.25	0.91	1.30	12.38	1.12
MOO:SBO (20:80)	3.79 ± 0.15	3.33 ± 0.19	3.01 ± 0.19	2.73 ± 0.13	2.61 ± 0.13	2.54 ± 0.12	2.10 ± 0.07	0.95	1.69	29.15	1.43
MOO:SBO (40:60)	5.79 ± 0.23	5.53 ± 0.27	4.98 ± 0.23	4.68 ± 0.20	4.66 ± 0.16	4.32 ± 0.14	4.21 ± 0.08	0.95	1.58	100.48	2.00
MOO:SBO (60:40)	6.96 ± 0.31	6.41 ± 0.36	6.31 ± 0.31	5.99 ± 0.34	5.77 ± 0.20	5.64 ± 0.21	5.56 ± 0.22	0.94	1.40	32.07	1.32
MOO:SBO (80:20)	7.51 ± 0.28	7.21 ± 0.29	6.99 ± 0.22	6.54 ± 0.26	6.48 ± 0.28	6.33 ± 0.22	6.22 ± 0.30	0.95	1.28	11.87	1.12

Bold values are for the pure substrate oils.
MOO, *Moringa oleifera* oil; SFO, sunflower oil; SBO, soybean oil.
[a] Values are means ± SD of three separate determinations.
[b] Decrease in IP from initial with respect to storage period.
[c] % Increase in IP with respect to blending of MOO.

flower kernel oil with *S. birrea* oil and melon bug oil, the oxidative stability in the rancimat test was improved from 47% to 147% (*S. birrea* oil) and from 5% to 68% (melon bug oil) compared to the sunflower kernel oil as control, with increasing parts of *S. birrea* oil and melon bug oil, respectively (Mariod et al., 2005).

Table 3 shows the effect of different blends of MOO with SFO and SBO on the development of PV, which measures hydroperoxide oxidation products of the oils (McGinely, 1991), during storage of the oils at ambient temperature for a period of 6 months. Addition of MOO to the SFO and SBO resulted in a marked decline in their PVs, thus showing enhancement of the oxidative state of these substrate oils. This decline in PV was MOO concentration dependent. The rate of increase of PV was slowest in the MOO:SBO (80:20) blend, as compared with MOO:SFO (80:20) and other blended oils and thus showed the MOO:SBO (80:20) blend to be least susceptible to oxidation. It appears that each increment (20%) of MOO significantly ($P \leqslant 0.05$) improved the oxidative stability of the oils under investigation. Blending of MOO with SFO and SBO at the level of 80:20% resulted in reduction of PV from 12.7 to 6.31 (50.5% reduction) and from 9.98 to 5.09 (49.0% reduction), respectively, as calculated at the end of storage period of 6 months. The periodical measurement of PV of the substrate and blended oils revealed that every 20% addition of MOO in SFO and SBO reduced their PV by average values of 16.0% and 15.2%, respectively (factors of 0.84 and 0.85, respectively).

Results in Table 3 also show that PVs of all the oil samples (pure oil and blends) increased with increase in storage period and followed the order: MOO < MOO:SBO (80:20) < SBO < MOO:SFO (80:20) < SFO. A slower rate of increment in PV of MOO (3.24 from initial) and MOO:SFO (5.98–11.1 from initial), MOO:SBO (4.76–8.26 from initial) blends compared with those of SFO (12.1 from initial) and SBO (9.37 from initial) might be attributed the high amounts of oleic acid (less susceptible to oxidation) and linoleic acids (more prone to oxidation) present in the former and the latter, respectively. Mariod et al. (2005) investigated the effects of different blends of sunflower kernel oil and *S. birrea* oil on the development of PV during a storage test and reported that the blends of 10% *S. birrea* oil with sunflower kernel oil showed marked improvement in the oxidative stability in comparison to pure sunflower kernel oil. Increase in the amount of *S. birrea* oil in the blends has been reported to cause drastic increase in the oxidative stability. Padmavathy et al. (2001) reported that sensory attributes of colour and taste of vegetable oils could be improved by blending, because the blends may meet the major objective of storage stability. Further, he also reported that, on storage, there was a significant increase ($p < 0.05$) in the PV of different pure and blended vegetable oils. Allam (2001) studied the oxidative stability of sunflower oil blended with nine oils distinguished by their high oleic acid contents. Monika, Franciszek, Stanislaw, and Stanislaw (2002) reported that

Table 3
Peroxide value of MOO, SFO, SBO, MOO:SFO and MOO:SBO during storing at ambient temperature (6 months)

Oils	Peroxide value ($meqO_2\ kg^{-1}$ of oil)[a] storage period (months)							R^2	Increase in PV from initial[b]	% Decrease in PV[c]	Factor
	0	1	2	3	4	5	6				
MOO	**0.23 ± 0.01**	**1.50 ± 0.09**	**2.01 ± 0.12**	**2.10 ± 0.10**	**3.02 ± 0.21**	**3.30 ± 0.23**	**3.47 ± 0.17**	**0.93**	**3.24**	–	–
SFO	**0.59 ± 0.03**	**3.50 ± 0.23**	**5.30 ± 0.21**	**9.03 ± 0.63**	**11.01 ± 0.55**	**11.31 ± 0.50**	**12.72 ± 0.76**	**0.95**	**12.1**	–	–
SBO	**0.61 ± 0.04**	**1.30 ± 0.09**	**2.51 ± 0.21**	**5.10 ± 0.22**	**8.31 ± 0.60**	**9.03 ± 0.59**	**9.98 ± 0.59**	**0.96**	**9.37**	–	–
MOO:SFO (20:80)	0.53 ± 0.04	2.70 ± 0.21	5.70 ± 0.55	6.90 ± 0.57	9.20 ± 0.58	11.01 ± 0.76	11.62 ± 0.76	0.98	11.1	8.65	0.91
MOO:SFO (40:60)	0.45 ± 0.02	3.11 ± 0.22	3.91 ± 0.19	4.91 ± 0.25	7.06 ± 0.59	9.10 ± 0.61	9.70 ± 0.56	0.98	9.25	16.5	0.83
MOO:SFO (60:40)	0.39 ± 0.03	2.70 ± 0.22	3.31 ± 0.23	5.10 ± 0.21	6.31 ± 0.57	6.80 ± 0.27	7.95 ± 0.32	0.97	7.56	18.0	0.82
MOO:SFO (80:20)	0.33 ± 0.02	1.90 ± 0.12	3.02 ± 0.20	4.81 ± 0.24	5.03 ± 0.30	6.10 ± 0.43	6.31 ± 0.44	0.95	5.98	20.8	0.79
MOO:SBO (20:80)	0.55 ± 0.03	1.01 ± 0.07	2.91 ± 0.20	5.71 ± 0.34	7.30 ± 0.57	7.60 ± 0.53	8.81 ± 0.52	0.96	8.26	11.7	0.88
MOO:SBO (40:60)	0.48 ± 0.03	2.11 ± 0.12	3.52 ± 0.17	4.32 ± 0.22	6.72 ± 0.47	7.11 ± 0.42	7.95 ± 0.47	0.97	7.47	9.66	0.90
MOO:SBO (60:40)	0.41 ± 0.02	1.12 ± 0.09	2.11 ± 0.12	3.91 ± 0.27	6.13 ± 0.33	6.01 ± 0.30	6.81 ± 0.41	0.95	6.40	14.5	0.86
MOO:SBO (80:20)	0.33 ± 0.01	1.10 ± 0.07	1.31 ± 0.09	2.10 ± 0.12	3.91 ± 0.21	4.90 ± 0.25	5.09 ± 0.30	0.95	4.76	25.2	0.75

Bold values are for the pure substrate oils.
MOO, *Moringa oleifera* oil; SFO, sunflower oil; SBO, soybean oil.
[a] Values are means ± SD of three separate determinations.
[b] Increase in PV from initial with respect to storage period.
[c] % Decrease in PV with respect to blending of MOO.

Table 4
Iodine value of MOO, SFO, SBO, MOO:SFO and MOO:SBO during storage at ambient temperature (6 months)

Oils	Iodine value (g of I 100 g^{-1} of oil)[a] storage period (months)							R^2	Decrease in IV from initial[b]	% Decrease in IV[c]	Factor
	0	1	2	3	4	5	6				
MOO	**69.8 ± 3.48**	**69.2 ± 3.46**	**68.8 ± 3.44**	**68.1 ± 3.40**	**67.0 ± 3.34**	**66.0 ± 3.30**	**65.3 ± 3.26**	**0.98**	**4.42**	–	–
SFO	**137 ± 3.85**	**136 ± 6.78**	**135 ± 6.74**	**134 ± 6.69**	**132 ± 6.59**	**129 ± 6.45**	**127 ± 6.36**	**0.96**	**9.69**	–	–
SBO	**133 ± 6.77**	**130 ± 6.59**	**128 ± 6.45**	**128 ± 6.36**	**127 ± 6.36**	**126 ± 6.33**	**125 ± 7.50**	**0.91**	**8.29**	–	–
MOO:SFO (20:80)	125 ± 7.50	123 ± 7.39	122 ± 7.26	121 ± 7.25	120 ± 8.34	119 ± 8.32	118 ± 7.02	0.98	7.08	7.37	0.93
MOO:SFO (40:60)	112 ± 7.05	112 ± 7.71	110 ± 7.74	109 ± 6.65	108 ± 6.58	107 ± 6.65	105 ± 6.33	0.99	7.01	11.0	0.89
MOO:SFO (60:40)	95.0 ± 5.23	94.4 ± 6.01	93.7 ± 5.68	92.8 ± 5.56	91.8 ± 5.49	90.1 ± 4.66	88.6 ± 6.16	0.96	6.44	15.7	0.84
MOO:SFO (80:20)	85.0 ± 4.35	83.0 ± 4.09	81.8 ± 4.06	81.0 ± 4.35	80.6 ± 4.00	79.9 ± 5.29	79.0 ± 5.44	0.94	6.02	10.8	0.89
MOO:SBO (20:80)	116 ± 6.98	116 ± 6.94	115 ± 6.87	113 ± 6.66	111 ± 7.77	110 ± 6.58	109 ± 6.65	0.97	6.91	12.7	0.87
MOO:SBO (40:60)	105 ± 6.30	104 ± 6.26	104 ± 7.25	103 ± 6.15	101 ± 6.05	99.4 ± 5.96	98.1 ± 5.88	0.98	6.90	10.2	0.90
MOO:SBO (60:40)	93.5 ± 5.56	92.4 ± 5.52	91.9 ± 5.46	90.9 ± 4.60	89.1 ± 5.37	88.3 ± 6.15	87.6 ± 4.35	0.98	5.93	10.7	0.89
MOO:SBO (80:20)	80.9 ± 4.01	79.7 ± 4.78	79.0 ± 5.29	78.2 ± 5.47	77.0 ± 5.39	76.1 ± 4.56	75.1 ± 4.50	0.99	5.81	14.3	0.86

Bold values are for the pure substrate oils.
MOO, *Moringa oleifera* oil; SFO, sunflower oil; SBO, soybean oil.
[a] Values are means ± SD of three separate determinations.
[b] Increase in IV from initial with respect to storage period.
[c] % Decrease in IV with respect to blending of MOO.

Table 5
Polymer contents of MOO, SFO, SBO, MOO:SFO and MOO:SBO during heating performance test[a]

Oils	Polymer contents[b] (%) (heating cycles)								R^2	Increase in polymer content from initial[c]	% Decrease in polymer content[d]	Factor
	0	1	2	3	4	5	6	7				
MOO	**0.11 ± 0.01**	**1.00 ± 0.05**	**2.31 ± 0.11**	**4.20 ± 0.21**	**6.80 ± 0.33**	**8.70 ± 0.43**	**10.9 ± 0.54**	**13.5 ± 0.86**	**0.98**	**13.4**	–	–
SFO	**0.56 ± 0.03**	**1.58 ± 0.07**	**3.32 ± 0.16**	**6.10 ± 0.30**	**9.80 ± 0.49**	**12.8 ± 0.65**	**19.3 ± 1.14**	**22.4 ± 0.65**	**0.96**	**21.8**	–	–
SBO	**0.34 ± 0.02**	**1.43 ± 0.08**	**3.30 ± 0.17**	**6.00 ± 0.28**	**8.75 ± 0.43**	**12.5 ± 0.66**	**15.5 ± 1.11**	**21.2 ± 1.04**	**0.96**	**20.9**	–	–
MOO:SFO (20:80)	0.52 ± 0.03	1.11 ± 0.05	3.01 ± 0.12	5.86 ± 0.31	9.35 ± 0.56	12.5 ± 0.50	18.0 ± 0.71	20.8 ± 1.02	0.96	20.3	6.93	0.93
MOO:SFO (40:60)	0.38 ± 0.02	0.88 ± 0.03	2.65 ± 0.15	5.63 ± 0.28	9.09 ± 0.55	12.2 ± 0.50	17.4 ± 0.70	19.4 ± 1.04	0.97	19.0	7.10	0.93
MOO:SFO (60:40)	0.22 ± 0.01	0.69 ± 0.02	2.22 ± 0.13	5.06 ± 0.21	8.53 ± 0.56	11.7 ± 0.51	14.7 ± 0.65	16.7 ± 1.10	0.98	16.5	13.8	0.86
MOO:SFO (80:20)	0.18 ± 0.01	0.61 ± 0.03	1.92 ± 0.09	4.41 ± 0.18	7.31 ± 0.49	10.6 ± 0.46	13.2 ± 0.66	15.2 ± 0.99	0.97	15.0	8.93	0.91
MOO:SBO (20:80)	0.30 ± 0.02	0.98 ± 0.04	2.83 ± 0.15	5.31 ± 0.29	8.02 ± 0.54	11.8 ± 0.48	15.0 ± 0.50	19.6 ± 0.98	0.96	19.3	7.69	0.94
MOO:SBO (40:60)	0.27 ± 0.02	0.86 ± 0.05	2.33 ± 0.10	4.83 ± 0.19	7.63 ± 0.39	11.0 ± 0.44	14.8 ± 0.52	18.5 ± 0.92	0.96	18.2	5.47	0.94
MOO:SBO (60:40)	0.19 ± 0.01	0.81 ± 0.04	1.98 ± 0.09	4.03 ± 0.20	6.86 ± 0.45	10.1 ± 0.46	13.2 ± 0.79	16.1 ± 0.89	0.96	15.9	12.9	0.87
MOO:SBO (80:20)	0.17 ± 0.01	0.44 ± 0.02	1.10 ± 0.05	3.79 ± 0.15	6.97 ± 0.38	9.69 ± 0.41	12.8 ± 0.62	14.9 ± 1.01	0.96	14.7	7.51	0.92

Bold values are for the pure substrate oils.
MOO, *Moringa oleifera* oil; SFO, sunflower oil; SBO, soybean oil.
[a] Heating at 180 °C for 42 h (6 h heating cycle per day).
[b] Values are means ± SD of three separate determinations.
[c] Increase in polymer contents from initial with respect to heating cycles.
[d] % Decrease in polymer contents with respect to blending.

Table 6
Total polar components of MOO, SFO, SBO, MOO:SFO and MOO:SBO during heating performance test[a]

Oils	Total polar components[b] (%) (heating cycles)								R^2	Increase in TPC from initial[c]	% Decrease in TPC[d]	Factor
	0	1	2	3	4	5	6	7				
MOO	**2.50 ± 0.12**	**3.75 ± 0.18**	**6.80 ± 0.34**	**9.80 ± 0.68**	**12.4 ± 0.74**	**13.9 ± 0.91**	**15.6 ± 0.78**	**19.0 ± 0.95**	**0.99**	**16.5**	–	–
SFO	**2.60 ± 0.13**	**3.77 ± 0.18**	**8.10 ± 0.48**	**11.4 ± 0.57**	**15.2 ± 0.60**	**20.3 ± 0.81**	**22.9 ± 0.92**	**27.2 ± 0.48**	**0.99**	**24.6**	–	–
SBO	**2.53 ± 0.12**	**3.76 ± 0.18**	**8.10 ± 0.48**	**11.1 ± 0.44**	**14.8 ± 0.59**	**17.5 ± 0.87**	**21.4 ± 1.06**	**26.0 ± 0.52**	**0.99**	**23.5**	–	–
MOO:SFO (20:80)	2.60 ± 0.13	3.77 ± 0.18	7.91 ± 0.47	11.1 ± 0.55	14.8 ± 0.73	18.7 ± 0.93	20.8 ± 1.03	25.6 ± 1.28	0.99	23.0	5.67	0.94
MOO:SFO (40:60)	2.58 ± 0.15	3.76 ± 0.16	7.50 ± 0.35	11.0 ± 0.49	14.6 ± 0.55	18.6 ± 0.90	20.8 ± 0.95	24.0 ± 1.20	0.99	21.4	6.25	0.94
MOO:SFO (60:40)	2.53 ± 0.13	3.77 ± 0.19	7.50 ± 0.41	10.5 ± 0.53	14.5 ± 0.69	17.0 ± 0.83	19.3 ± 0.83	22.4 ± 1.23	0.99	19.8	6.91	0.93
MOO:SFO (80:20)	2.51 ± 0.14	3.75 ± 0.18	7.33 ± 0.31	10.4 ± 0.46	13.0 ± 0.71	15.5 ± 0.81	17.0 ± 0.78	20.8 ± 1.22	0.99	18.2	7.16	0.93
MOO:SBO (20:80)	2.53 ± 0.12	3.75 ± 0.17	7.91 ± 0.29	10.7 ± 0.54	14.6 ± 0.64	16.9 ± 0.76	21.0 ± 0.92	24.6 ± 0.98	0.99	22.1	5.27	0.95
MOO:SBO (40:60)	2.51 ± 0.14	3.76 ± 0.17	7.30 ± 0.28	10.6 ± 0.56	14.0 ± 0.66	16.3 ± 0.77	19.3 ± 0.81	24.0 ± 0.91	0.99	21.5	2.52	0.97
MOO:SBO (60:40)	2.52 ± 0.15	3.75 ± 0.16	7.09 ± 0.30	10.0 ± 0.56	13.5 ± 0.61	15.5 ± 0.72	18.4 ± 0.85	21.4 ± 0.88	0.99	18.8	11.0	0.89
MOO:SBO (80:20)	2.51 ± 0.12	3.75 ± 0.15	6.91 ± 0.28	9.97 ± 0.59	12.6 ± 0.62	14.6 ± 0.73	16.2 ± 0.81	19.9 ± 0.99	0.99	17.4	6.74	0.93

Bold values are for the pure substrate oils.
MOO, *Moringa oleifera* oil; SFO, sunflower oil; SBO, soybean oil.
[a] Heating at 180 °C for 42 h (6 h heating cycle per day).
[b] Values are means ± SD of three separate determinations.
[c] Increase in total polymer components from initial with respect to heating cycles.
[d] % Decrease in total polymer components with respect to blending.

the oxidative stability of 1:1 (v/v) rapeseed/palm olein blend was improved up to 60% in comparison with rapeseed oil, while Shiota, Konishi, and Tatsumi (1999) demonstrated an improved oxidative stability of fish oil blended with butter. It is obvious, from the present storage test, that blending of MOO has significantly increased the oxidative stability of both the substrate oils. The improvement in the oxidative stability of the investigated oils might be attributed to the blending of MOO. MOO is a naturally high-oleic oil and such high-oleic oils are now gaining much importance for their increased stability, nutritional and medicinal attributes (Solfrizzi et al., 1999; Wong et al., 1991). The reduction in PV, as exhibited by blended formulations, was mainly because of the reduction of unsaturated $C_{18:2}$ at the expense of $C_{18:1}$. The reported rates of oxidation of $C_{18:1}$ and $C_{18:2}$ are of the order of 1:12 (Reynhout, 1991).

Table 4 shows the effect of blending and storage conditions on iodine value (IV) of pure and blended oils. The addition of MOO at 0–80% to SFO and SBO resulted in the decline of IV of SFO and SBO from 137 to 85 and 133 to 80.9; reductions of 38.0% and 39.4%, respectively and this was almost comparable with the reductions (38.0% and 40.0%) at the end of storage period in SFO and SBO, respectively. The measurement of IV of blended oils revealed that every 20% addition of MOO in SFO and SBO reduced their IVs by average values of 11.2% and 12.0%, respectively (factors of 0.89 and 0.88, respectively). Storage resulted in decrease of IV of all pure and blended oils. The decrease in IV increased with increase of time of storage. MOO generally showed the lowest decrease in IV (4.42), while SFO and SBO showed relatively higher decreases in IV (9.69 and 8.29, respectively). MOO:SFO and MOO:SBO blends generally showed lower decreases in IV than did pure SFO on SBO. The periodic analysis of pure and blended oils as function of storage time revealed a decline in IV, and R^2 ranged from 0.91 to 0.99. The reduction in IV, as exhibited by blended formulations, was mainly because of the reduction of unsaturated $C_{18:2}$ at the expense of $C_{18:1}$. Padmavathy et al., 2001 reported the lowest decrease in IV in crude palm oil, highest decrease in IV in sunflower oil and the decrease for the blend of crude palm oil with sunflower oil was between these, when the oils were stored for 3 months at room temperature.

Table 5 shows the extent of changes in polymer contents of pure substrate and blended oils as analyzed during the course of the heating performance test (180 °C; 42 h, 6 h heating cycle). The estimation of polymer contents of oils during the frying/heating process is an important criterion for evaluating the thermal stability of oils (Tain & Dasgupta, 1999). It is evident from the results of the present analysis that each 20% addition of MOO to the SFO and SBO resulted in average decreases of 9.19% and 8.40% in the polymer contents of these substrate oils, respectively. It appears from the results that every 20% addition of MOO decreased the polymer contents of SFO and SBO by factors of 0.91 and 0.92, respectively. This reduction in polymer content of SFO and SBO might be due, in part, to the high stability of the MOO. Addition of MOO at a level of 80% caused a notable decline in the polymer contents of SFO and SBO from 22.4% to 15.2% and 21.2% to 14.9%, reductions of 32.0% and 29.7%, respectively, thus showing enhancement of heating/frying stability. The polymer contents of substrate and blended oils increased as the heating time increased and the increase in the case of MOO was lowest (13.4 from initial), while the increase in polymer contents of SFO was highest (21.8 from initial) in comparison with SBO and other oil blends, as noted after the completion of seven heating cycles (42 h of heating). The overall increment in the polymer contents of substrate oils and blended oils, as a function of each heating cycle, had R^2 values ranging from 0.96 to 0.98.

Table 6 shows the level of changes in the total polar components (TPC) of pure substrate oils and blended oils as analyzed following a heating performance test at 180 °C for 42 h (6 h heating cycle). As a result of MOO blending, the amounts of oxidized total polar components of SFO and SBO were significantly ($P < 0.05$) reduced. This decline was MOO concentration dependent. It is clear from the results that each 20% addition of MOO in SFO and SBO resulted in decreases of the TPC at levels of 6.50% and 6.39%, respectively. When a factorial relation was established, it was noted that every 20% addition of MOO resulted in decrease in TPC by a factor of 0.94, respectively. It was found that addition of MOO in SFO and SBO at the level of 80% reduced the TPC of these oils from 27.2 to 20.8 (23.6% reduction) and 26.0 to 19.9 (23.4% reduction), respectively. The TPCs of the substrate oils increased as a function of heating time. The increases in TPC of MOO, SFO and SBO from initial values, as estimated after the 42 h heating period, were 16.5, 24.6 and 23.5, respectively and followed a linear regression relationship with R^2 value of 0.99. On the basis of the present findings, it appears that proper blending of high linoleic oils, such as SFO and SBO, with MOO can result in oil blends which could meet nutritional needs with improved stability for domestic cooking and deep-frying.

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