Received: 27 March 2021 | Revised: 2 July 2021 | Accepted: 22 September 2021

DOI: 10.1111/jfpp.16015

Journal of Food Processing and Preservation | Institute of Food Science + Technology | WILEY

ORIGINAL ARTICLE

Impact of intermittent frying on chemical properties, fatty acid composition, and oxidative stability of 10 different vegetable oil blends

Amarbir Kaur[1] | Balwinder Singh[2] | Amritpal Kaur[1] | Madhav P. Yadav[3] | Narpinder Singh[1]

[1]Department of Food Science and Technology, Guru Nanak Dev University, Amritsar, India

[2]P.G. Department of Biotechnology, Khalsa College, Amritsar, India

[3]Eastern Regional Research Center, Agricultural Research Service, United States Department of Agriculture, Wyndmoor, Pennsylvania, USA

Correspondence
Balwinder Singh, P.G. Department of Biotechnology, Khalsa College, Amritsar 143002, Punjab, India.
Email: bbs171@rediffmail.com

Amritpal Kaur, Department of Food Science and Technology, Guru Nanak Dev University, Amritsar 143005, Punjab, India.
Email: amritft33@yahoo.co.in

Madhav P. Yadav, Eastern Regional Research Center, Agricultural Research Service, United States Department of Agriculture, 600 East Mermaid Lane, Wyndmoor, Pennsylvania 19038, USA.
Email: madhav.yadav@usda.gov

Funding information
University Grants Commission; Indo-US Science and Technology Forum, Grant/Award Number: 2019/072; Science and Engineering Research Board, Grant/Award Number: EEQ/2020/000565 and SB/WEA/09/2017

Abstract

Impact on chemical properties, viscosity, oxidative stability, and fatty acid composition (FAC) of 10 vegetable oil blends (VOBs) following intermittent frying of chickpea splits was studied. The peroxide (PV), p-Anisidine (p-AV), acid (AV) value, and viscosity of VOBs increased, while oxidative stability index (OSI) decreased by increasing frying cycles (FCs). VOB-3 and VOB-7 exhibited a minimum change in PV, AV, p-AV, viscosity, and OSI with an increment in FCs. Oil uptake increased with an increment in FCs and the lowest change observed in VOB-3 (6.0%–13.7%). VOB-7, VOB-8, and VOB-6 exhibited lower changes in ω6/ω3 ratio, saturated and unsaturated fatty acids contents, respectively with an increment in FCs. VOB-5 and VOB-9 exhibited higher variation in FAC and FTIR peaks while atherogenic and thrombogenic index of VOBs varied slightly with an increment in FCs. Based on the results, VOB-3 and VOB-7 were found suitable for intermittent frying of chickpea splits.

Practical applications

Vegetable oil blends suitable for deep fat frying were identified by comparing quality and stability characteristics of 10 VOBs during intermittent frying of chickpea splits. VOB-3 (CNO + SBO [80:20]) and VOB-7 (CNO + RBO + SBO [60:20:20]) exhibited minimum changes in chemical properties, viscosity, and OSI with an increment in FCs and had balanced FAC (ω6/ω3 ratio). Thus, VOB-3 and VOB-7 are suitable for intermittent frying among the studied VOBs.

1 | INTRODUCTION

Deep fat frying is the oldest and popular cooking practice used worldwide for the preparation of different foodstuffs (Choe & Min, 2007). It involves cooking food at high temperature by immersing in heated oil for simultaneous heat and mass transfer (Multari et al., 2019). The deep-frying process imparts desirable flavor, color, texture, and sensory attributes to food, and thus widely preferred by consumers for food

Abbreviations: AI, atherogenic index; AV, acid value; CNO, canola oil; CSO, cottonseed oil; FAs, fatty acids; FAC, fatty acid composition; FCs, frying cycles; FFAs, free fatty acids; FTIR, Fourier transform infrared spectroscopy; MUFAs, monosaturated fatty acids; OSI, oxidative stability index; p-AV, p-Anisidine value; PUFAs, polyunsaturated fatty acids; PV, peroxide value; RBO, rice bran oil; SBO, soybean oil; SFAs, saturated fatty acids; SFO, sunflower oil; TI, thrombogenic index; UFAs, unsaturated fatty acids; VOBs, vegetable oil blends; VOB-1, CNO + RBO (80:20); VOB-2, CNO + SFO (80:20); VOB-3, CNO + SBO (80:20); VOB-4, CNO + CSO (80:20); VOB-5, CNO + RBO + CSO (60:20:20); VOB-6, CNO + RBO + SFO (60:20:20); VOB-7, CNO + RBO + SBO (60:20:20); VOB-8, CNO + RBO + CSO (50:30:20); VOB-9, CNO + RBO + SFO (50:30:20); VOB-10, CNO + RBO + SBO (50:30:20).

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

preparations (Zribi et al., 2014). The vegetable oils are the major ingredient in the fried food products, and they are repeatedly heated and reused to ensure cost-effectiveness (Nayak et al., 2016). Owing to the presence of high temperature, moisture, and oxygen in food, the frying process leads to chemicals reactions (such as hydrolysis, thermal oxidation, and polymerization) and production of free radicals, toxic, and anti-nutritional compounds in frying oil (Choe & Min, 2007; Tavakoli et al., 2019). The thermal oxidation results in the formation of oxidation products (primary and secondary) and hydrolysis breakdown triglycerides in the presence of water and steam into glycerols, glycerides, and free fatty acids (FAs). The complex reactions like polymerization and cyclization during deep-frying produce several volatile and non-volatile metabolites in oils (Kaur et al., 2020; Multari et al., 2019). The products of chemical reactions such as free FAs, alcohols, cyclic compounds, dimers, oligomers, and polymers alter the chemical and physical properties of frying oil (Kaur et al., 2020; Nayak et al., 2016).

During intermittent or discontinuous deep-frying process, the oil is reused and, consequently, its degradation is more as compared with other cooking methods (Dobarganes & Márquez-Ruiz, 2015). The products generated from adverse chemical reactions in repeatedly heated oil get absorbed in foodstuff and cause detrimental health effects (Nayak et al., 2016; Tavakoli et al., 2019). The consumption of heated oils containing toxic substances and free radicals can cause cardiovascular diseases (Ng et al., 2014), hypertension (Soriguer et al., 2003), genotoxicity (Dung et al., 2006), carcinogenicity (Srivastava et al., 2010), aging, and other degenerative diseases (Soleimanifar et al., 2019). The harmful effect of fried foods is attributed to the deterioration of the quality of oil during the heating process. Fatty acid composition (FAC) of refined oils have important role in maintaining the quality during deep-fat-frying process (Kaur et al., 2020). The oils containing high content of polyunsaturated fatty acids (PUFAs) are more liable to oxidation and degradation than the oil containing high level of saturated fatty acids (SFAs). While more SFAs are not desirable as they contribute to atherogenicity and thrombogenicity of oils (Kaur et al., 2020). Thus, the oils having balanced FAC with desired ω6/ω3 ratio (5–10:1), good oxidative stability, and nutritional value are required in human diet to prevent certain diseases (Kaur et al., 2020; Ramadan, 2013).

Oil blending is a common technological method for the improvement of physicochemical, nutritional, textural, organoleptic characteristics, and oxidative stability of vegetable oils (Hashempour-Baltork et al., 2016; Kiralan et al., 2016). Edible vegetable oils can be modified by blending for the improvement of chemical properties, oxidative stability, and nutritional characteristics (Kiralan et al., 2016, 2017). The vegetable oil blends (VOBs) with improved thermal stability and desired nutritional value are required in the food industry for deep-fat frying applications (Hashempour-Baltork et al., 2016; Koohikamali & Alam, 2019). The blended oil takes advantage of the oxidative stability and quality characteristics of different oils and improves the sensory attributes of the final food product (Hashempour-Baltork et al., 2016). Moreover, the use of oil mixtures in the frying process retard the oxidative and hydrolytic rancidity and delay deterioration in fried food products during storage (Chotimarkorn & Silalai, 2008; Hashempour-Baltork et al., 2016).

The studies related to quality characteristics and frying stability of different VOBs are of prime importance. The comparative study of changes in quality and stability characteristics of different VOBs during intermittent frying process is necessary to investigate the most appropriate oil blend for deep-fat frying operations. Thus the present study formulated 10 VOBs and compared the impact of frying cycles (FCs) on oxidative stability index (OSI), chemical properties, viscosity, oil uptake, FAC, ω6/ω3 ratio, thrombogenicity (TI) and atherogenicity (AI) index, and FTIR spectra of these oils. The VOBs that maintain good nutritional quality and oxidative stability characteristics along with balanced fatty acid profile during intermittent deep-frying operations were identified.

2 | MATERIALS AND METHODS

2.1 | Materials

The black chickpea splits, soybean oil (SBO), rice bran oil (RBO), canola oil (CNO), cottonseed oil (CSO), and sunflower oil (SFO) were purchased from the local market of Amritsar, India. All the chemicals used were of analytical laboratory grade.

2.2 | Preparation of vegetable oil blends (VOBs)

Ten VOBs (VOB-1 to VOB-10) were prepared by mixing vegetable oils in different ratios followed by stirring at 200 rpm for 15 min. The composition of VOBs were as follow: VOB-1: CNO 80% + RBO 20%; VOB-2: CNO 80% + SFO 20%; VOB-3: CNO 80% + SBO 20%; VOB-4: CNO 80% + CSO 20%; VOB-5: CNO 60% + RBO 20% + CSO 20%; VOB-6: CNO 60% + RBO 20% + SFO 20%; VOB-7: CNO 60% + RBO 20% + SBO 20%; VOB-8: CNO 50% + RBO 30% + CSO 20%; VOB-9: CNO 50% + RBO 30% + SFO 20%; VOB-10: CNO 50% + RBO 30% + SBO 20%.

2.3 | Frying process

The chickpea splits were cleaned, hydrated, and fried by the following procedure described by Kaur et al. (2020). The hydrated chickpea splits had a moisture content of 48.54 ± 0.68%. The frying pot of the electrical fryer was filled with VOB (1 L) and heated at 175°C for 10 min. The frying of chickpea splits was carried out at 175°C for 2 min in VOBs. The 100 g of hydrated chickpea splits deep-fried for 2 min and drained for 1 min in a frying basket (steel wire) make up one frying cycle (FC). The oil uptake (OU) was estimated as described by Kaur et al. (2020) during frying in different VOBs. The fryer was put off and VOB was cooled to room temperature after each FC. Hundred milliliter of VOB was collected from the fryer after FCs (first, fifth, and tenth FC), filtered, and stored (at −20°C) in sealed amber colored bottles till analysis. The VOB in the fryer was

replenished to 1 L and re-heating at 175°C for 10 min before starting the next FC.

2.4 | Chemical properties

The peroxide (PV), acid (AV), and p-Anisidine (p-AV) values of fresh VOBs and after FCs were determined using official methods (Cd 8b-90, Ca 5a-40, and Cd 18-90, respectively) of American Oil Chemists' Society (American Oil Chemists' Society (AOCS), 2017; American Oil Chemists' Society (AOCS), 1997).

2.5 | Oxidative stability index (OSI)

OSI of fresh VOBs and after FCs was determined using the procedure described by Kaur et al. (2020). OSI was measured using Professional 892 Rancimat (Metrohm, Switzerland) at 120 ± 1.6°C using 10 L/h of air inflow conditions and data reported as induction period in hours (h).

2.6 | Viscosity

The viscosity of fresh VOBs and after FCs was determined according to the method described by Kaur et al. (2019) using MCR 102 Rheometer (Anton Paar, Austria).

2.7 | Oil uptake (OU)

The OU by the fried chickpea splits collected after different FCs was determined according to the method described by Kaur et al. (2020).

2.8 | Fatty acid composition (FAC)

The FAC of fresh VOBs and after FCs was studied according to the official method Ce-1h-05 of the American Oil Chemists' Society (AOCS, 1997) with slight modifications as described by Suri et al. (2020). The fatty acid methyl esters were analyzed by an Agilent 7820A Gas chromatography system equipped with FID and DB-WAX capillary column (Agilent Technologies, USA). The individual FA was identified (by comparing retention time with standard) and quantified (using peak area) as relative percentage of total FAs (g/100 g).

2.9 | Thrombogenic (TI) and Atherogenic (AI) index

TI and AI of VOBs were calculated according to following equations as described previously (Kaur et al., 2020):

$$TI = \frac{14{:}0 + 16{:}0 + 18{:}0}{(0.5\text{MUFAs}) + (0.5 \times \sum 18{:}3) + (3 \times \sum 18{:}2)}$$

$$AI = \frac{12{:}0 + 4 \times 14{:}0 + 6{:}0}{\sum \text{MUFAs} + \sum 18{:}3 + \sum 18{:}2}$$

In these equations, 12:0, 14:0, 16:0, 18:0, 18:2, 18:3, and MUFAs are lauric, myristic, palmitic, stearic, linoleic, linolenic, and monounsaturated FAs, respectively.

2.10 | FTIR spectroscopy

IR spectra of fresh VOBs and after FCs were obtained (32 scans/sample) using Vertex-70 FTIR Spectrometer (Brucker, Germany) equipped with ATR assembly as described previously (Suri et al., 2022). FTIR spectra were acquired in the absorbance range of 3500–500 cm^{-1} at 4 cm^{-1} resolution and corrected against the background spectrum of air. Three spectra were taken for each sample.

2.11 | Statistical analysis

All experiments for VOBs were carried out in triplicate, and data were expressed as mean value of the triplicate ± standard deviation. Pearson correlation and principal component analysis was applied to evaluate the impact of FCs on VOBs and to determine the relations among the studied parameters. The two-way ANOVA was performed to know the impact of blending and intermittent frying on various characteristics of oils. For analysis of data, statistical tools were employed using Minitab Software (version14.12.0, Minitab).

3 | RESULTS AND DISCUSSION

3.1 | Effect of FCs on AV of VOBs

The AV of fresh VOBs and after FCs is listed in Table 1. The AV of fresh VOBs ranged from 0.06 to 0.13 mg KOH/g, which falls within the range (0.6 mg KOH/g) recommended for refined oils (FAO/WHO, 2009). Among fresh VOBs, the lowest AV (0.06 mg KOH/g) was observed in VOB-5. The AV of VOBs increased with increment in FCs. *F* values revealed higher significant effect of FCs on AV than the VOBs ($p \leq .005$, Table S1). After first, fifth, and tenth FC, AV of VOBs ranged from 0.26 to 0.60, 0.37 to 0.86, and 0.37 to 1.20 mg KOH/g, respectively. The VOB-3 and VOB-10 exhibited minimum and maximum change in AV with increment in FCs, respectively. Changes in AV indicate the release of free fatty acids (FFAs) due to hydrolytic breakdown of triacylglycerol in oils at high temperature during the deep-frying operations (Kaur et al., 2020). The FFAs released in oils are more prone to thermal oxidation under deep-frying conditions (Zribi et al., 2014). A study conducted by Ramadan et al. (2006) described an increase in FFAs content of two VOBs (SFO + palm olein and CSO + palm olein) during intermittent frying of French fries. Similarly an increase in FFAs content were

TABLE 1 Effect of frying cycles on chemical properties, oxidative stability, oil uptake and viscosity of vegetable oil blends

VOBs	Ratio	FC	AV (mg KOH/g)	PV (meqO_2/kg)	p-AV	OSI (h)	Viscosity (mPa.s)	OU (%)
VOB-1 (CNO + RBO)	80:20	0	0.07 ± 0.02^{a}	08.67 ± 0.41^{b}	1.16 ± 0.18^{b}	7.53 ± 0.08^{e}	57.29 ± 0.55^{a}	–
		1	0.37 ± 0.04^{c}	15.30 ± 0.57^{c}	1.22 ± 0.22^{b}	6.75 ± 0.07^{d}	62.12 ± 0.55^{b}	07.20 ± 0.2^{a}
		5	0.49 ± 0.03^{d}	18.00 ± 0.35^{c}	2.54 ± 0.35^{c}	3.34 ± 0.09^{b}	63.00 ± 0.60^{b}	10.60 ± 0.5^{b}
		10	0.82 ± 0.06^{f}	26.60 ± 0.74^{d}	4.41 ± 0.20^{e}	2.73 ± 0.06^{a}	64.87 ± 0.60^{b}	17.40 ± 0.6^{c}
VOB-2 (CNO + SFO)	80:20	0	0.07 ± 0.02^{a}	08.67 ± 0.18^{b}	0.60 ± 0.06^{a}	7.13 ± 0.08^{a}	57.65 ± 0.45^{a}	–
		1	0.30 ± 0.04^{c}	15.30 ± 0.81^{c}	0.66 ± 0.07^{a}	6.54 ± 0.07^{d}	59.93 ± 0.56^{a}	09.20 ± 0.3^{a}
		5	0.37 ± 0.03^{c}	24.00 ± 0.74^{d}	0.90 ± 0.09^{a}	3.25 ± 0.09^{b}	60.00 ± 0.50^{b}	15.40 ± 0.8^{b}
		10	0.49 ± 0.04^{d}	25.30 ± 0.57^{d}	2.29 ± 0.18^{c}	2.59 ± 0.05^{a}	60.31 ± 0.71^{b}	21.50 ± 0.4^{d}
VOB-3 (CNO + SBO)	80:20	0	0.07 ± 0.02^{a}	07.33 ± 0.35^{b}	0.50 ± 0.09^{a}	5.32 ± 0.08^{c}	55.02 ± 0.40^{a}	–
		1	0.26 ± 0.04^{b}	11.30 ± 0.57^{b}	0.51 ± 0.07^{a}	4.75 ± 0.07^{b}	58.56 ± 0.86^{a}	06.00 ± 0.2^{a}
		5	0.37 ± 0.04^{c}	22.60 ± 0.81^{d}	1.45 ± 0.18^{b}	3.17 ± 0.08^{a}	61.00 ± 0.42^{b}	09.00 ± 0.4^{a}
		10	0.37 ± 0.05^{c}	24.30 ± 0.81^{f}	2.26 ± 0.35^{c}	1.50 ± 0.06^{a}	61.29 ± 0.76^{b}	13.70 ± 0.3^{b}
VOB-4 (CNO + CSO)	80:20	0	0.07 ± 0.02^{a}	08.00 ± 0.41^{b}	0.38 ± 0.04^{a}	5.52 ± 0.10^{c}	57.00 ± 0.60^{a}	–
		1	0.49 ± 0.03^{d}	23.30 ± 0.51^{d}	0.45 ± 0.04^{a}	4.35 ± 0.08^{c}	59.41 ± 0.38^{a}	10.40 ± 0.3^{b}
		5	0.64 ± 0.07^{e}	33.30 ± 0.81^{e}	0.59 ± 0.06^{a}	1.72 ± 0.09^{a}	60.00 ± 0.50^{b}	17.70 ± 0.7^{c}
		10	0.75 ± 0.07^{f}	37.30 ± 0.57^{e}	3.00 ± 0.35^{d}	1.14 ± 0.06^{a}	61.75 ± 0.35^{b}	23.40 ± 0.5^{d}
VOB-5 (CNO + RBO + CSO)	60:20:20	0	0.06 ± 0.05^{a}	02.67 ± 0.19^{a}	0.75 ± 0.07^{a}	7.05 ± 0.10^{e}	62.67 ± 0.35^{b}	–
		1	0.34 ± 0.04^{c}	10.00 ± 0.74^{b}	0.89 ± 0.09^{a}	6.53 ± 0.07^{d}	63.94 ± 0.33^{b}	16.50 ± 0.5^{c}
		5	0.41 ± 0.04^{d}	12.00 ± 0.57^{b}	1.90 ± 0.18^{b}	2.86 ± 0.06^{a}	66.00 ± 0.25^{c}	20.50 ± 0.8^{c}
		10	0.49 ± 0.04^{d}	15.33 ± 0.51^{c}	3.56 ± 0.17^{d}	2.85 ± 0.07^{a}	68.31 ± 0.53^{c}	28.50 ± 0.6^{e}
VOB-6 (CNO + RBO + SFO)	60:20:20	0	0.08 ± 0.02^{a}	07.33 ± 0.35^{b}	1.56 ± 0.06^{b}	7.84 ± 0.06^{e}	60.51 ± 0.80^{b}	–
		1	0.56 ± 0.03^{e}	09.33 ± 0.41^{b}	1.77 ± 0.18^{b}	7.50 ± 0.06^{e}	63.00 ± 0.51^{b}	10.50 ± 0.4^{b}
		5	0.56 ± 0.04^{e}	14.67 ± 0.57^{c}	2.89 ± 0.35^{c}	3.84 ± 0.11^{b}	65.00 ± 0.65^{b}	14.90 ± 0.6^{b}
		10	0.60 ± 0.07^{e}	16.67 ± 0.35^{c}	3.90 ± 0.17^{d}	3.34 ± 0.07^{b}	67.46 ± 0.30^{c}	26.00 ± 0.8^{e}
VOB-7 (CNO + RBO + SBO)	60:20:20	0	0.08 ± 0.02^{a}	02.67 ± 0.19^{a}	1.46 ± 0.18^{b}	7.93 ± 0.10^{e}	60.29 ± 0.40^{b}	–
		1	0.41 ± 0.03^{d}	04.33 ± 0.22^{a}	1.90 ± 0.22^{b}	7.84 ± 0.09^{e}	61.60 ± 0.44^{b}	05.00 ± 0.3^{a}
		5	0.52 ± 0.03^{d}	9.67 ± 0.35^{c}	2.89 ± 0.35^{c}	4.05 ± 0.09^{c}	62.00 ± 0.40^{b}	11.70 ± 0.6^{b}
		10	0.86 ± 0.07^{f}	12.02 ± 0.74^{c}	3.78 ± 0.18^{d}	3.55 ± 0.08^{b}	62.94 ± 0.22^{b}	20.00 ± 0.4^{c}
VOB-8 (CNO + RBO + CSO)	50:30:20	0	0.08 ± 0.02^{a}	04.00 ± 0.22^{a}	1.45 ± 0.22^{b}	7.49 ± 0.08^{e}	62.11 ± 0.32^{b}	–
		1	0.49 ± 0.03^{d}	04.67 ± 0.41^{a}	1.78 ± 0.18^{b}	7.24 ± 0.09^{e}	63.95 ± 0.40^{b}	17.00 ± 0.7^{c}
		5	0.86 ± 0.06^{f}	10.67 ± 0.51^{b}	3.22 ± 0.12^{d}	3.04 ± 0.10^{b}	66.00 ± 0.21^{c}	23.20 ± 0.5^{d}
		10	1.16 ± 0.09^{g}	16.67 ± 0.57^{c}	3.40 ± 0.17^{d}	2.68 ± 0.04^{a}	68.05 ± 0.76^{c}	32.00 ± 0.7^{f}

(Continued)

TABLE 1 (Continued)

VOBs	Ratio	FC	AV (mg KOH/g)	PV (meqO_2/kg)	p-AV	OSI (h)	Viscosity (mPa.s)	OU (%)
VOB-9 (CNO + RBO + SFO)	50:30:20	0	0.13 ± 004^{b}	05.33 ± 0.22^{a}	2.15 ± 0.09^{c}	6.53 ± 0.09^{d}	62.33 ± 0.55^{b}	-
		1	0.60 ± 0.03^{e}	10.00 ± 0.51^{b}	2.42 ± 0.12^{c}	6.05 ± 0.14^{d}	62.44 ± 0.40^{b}	15.00 ± 0.5^{b}
		5	0.60 ± 0.07^{e}	11.33 ± 0.81^{b}	3.57 ± 0.17^{d}	3.12 ± 0.10^{b}	64.00 ± 0.31^{b}	19.80 ± 0.7^{c}
		10	0.86 ± 0.09^{f}	14.67 ± 0.57^{c}	4.47 ± 0.18^{e}	2.84 ± 0.09^{a}	66.05 ± 0.30^{c}	25.00 ± 0.5^{d}
VOB-10 (CNO + RBO + SBO)	50:30:20	0	0.13 ± 0.04^{b}	06.00 ± 0.41^{a}	1.82 ± 0.22^{b}	4.63 ± 0.06^{c}	62.29 ± 0.61^{b}	-
		1	0.60 ± 0.03^{e}	10.67 ± 0.19^{b}	3.11 ± 0.12^{d}	4.31 ± 0.09^{c}	64.95 ± 0.70^{b}	08.60 ± 0.3^{a}
		5	0.71 ± 0.07^{e}	12.00 ± 0.81^{b}	3.65 ± 0.17^{d}	2.24 ± 0.11^{a}	66.00 ± 0.31^{c}	15.70 ± 0.3^{b}
		10	1.20 ± 0.09^{g}	19.33 ± 0.57^{c}	4.17 ± 0.18^{e}	1.85 ± 0.07^{a}	70.27 ± 0.89^{d}	23.80 ± 0.5^{d}

Note: Values within the column with different alphabets are significantly different ($p \leq .05$).

Abbreviations: AV, acid value; CNO, canola oil; CSO, cottonseed oil; FC, frying cycle; OU, oil uptake; OSI, oxidative stability index; p-AV, p-Anisidine value; PV, peroxide value; RBO, rice bran oil; SBO, soybean oil; SFO, sunflower oil; VOBs, vegetable oil blends.

reported during deep-frying in different oils (Kaur et al., 2020; Song et al., 2017; Waghmare et al., 2018). A highly positive significant ($p \leq .005$) correlation was found between AV and FCs ($r = 0.667$) as given in Table 3. Similar correlation of FFAs with FCs was described in study conducted by Kaur et al. (2020).

3.2 | Effect of FCs on PV of VOBs

The PV indicates the development of primary oxidative products (peroxides and hydroperoxides) due to the oxidative deterioration of oils (Suri et al., 2020). The PV of VOBs (fresh and after first, fifth, and tenth FCs) is given in Table 1. The PV of fresh VOBs was noted in the range of 2.65 to 8.67 meq O_2/kg, with the lowest and highest for VOB-7 and VOB-2, respectively. The VOB-2 had high UFAs content compared with other VOBs (Table 2). The PV indicates the amount of O_2 bound in UFAs of the oil (Kaur et al., 2019). Our results showed that PV of fresh VOBs falls within the acceptable value of 10 meq O_2/kg (FAO/WHO, 2009). The PV of VOBs increases by addition of FCs, which indicates accumulation of peroxides due to the attack of free radical on UFAs in oils during intermittent frying process (Kaur et al., 2020). PV exhibited higher significant variation with FCs than the VOBs ($p \leq .005$, Table S1). After first, fifth, and tenth FC, the PV of VOBs ranged from 4.33 to 23.30, 9.67 to 33.30, and 12.02 to 37.30 meq O_2/kg, respectively. The highest and lowest PV after the tenth FC was noted in VOB-4 and VOB-7, respectively. A significant change in PV was observed in VOB-4 (23.30 to 33.30 meq O_2/kg), while a minor change (10.00 to 11.33 meq O_2/kg) was noticed in VOB-9 with an increment from first to the fifth FC. The increase in PV reflects the oxidative deterioration (formation of peroxides) of oil during intermittent frying process (Kaur et al., 2020; Ramadan et al., 2006). An increase in PV of two VOBs (SFO + palm olein and CSO + palm olein) during intermittent frying of French fries was reported by Ramadan et al. (2006). Liu et al. (2019) also observed a similar change in PV of palm oil and SFO by increasing frying time for 0 to 40 hr. PV exhibited a highly positive significant ($p \leq .005$) correlation with FCs ($r = 0.610$) and positive significant ($p \leq .05$) correlation with AV ($r = 0.342$) as given in Table 3. Similar positive correlation of PV with FCs and FFA content of refined vegetable oils was previously reported by Kaur et al. (2020) during intermittent frying process.

3.3 | Effect of FCs on p-AV of VOBs

The p-AV of fresh VOBs and after first, fifth, and tenth FCs is listed in Table 1. In fresh VOBs, the p-AV was in the range of 0.38 to 2.15, with the lowest in VOB-4 and highest in VOB-9, respectively. The lower p-AV of fresh oil indicates a lower lipid oxidative products level in that oil (Kaur et al., 2020). The p-AV of VOBs increased with the addition of FCs. The increase in p-AV relates with the formation of secondary products such as nonvolatile aldehydes (primarily 2-alkenals and 2,4-dienals) during deep-frying in oils

TABLE 2 Effect of frying cycles on fatty acid composition of vegetable oil blends

VOBs	Ratio	FC	C16:0 (Palmitic)	C18:0 (Stearic)	C20:0 (Arachidic)	C22:0 (Behnic)	C24:0 (Lignoceric)
VOB-1 (CNO + RBO)	80:20	0	5.06 ± 0.05^{a}	1.90 ± 0.08^{a}	0.59 ± 0.03^{b}	0.30 ± 0.03^{a}	Nd
		1	6.52 ± 0.05^{b}	1.90 ± 0.07^{a}	0.60 ± 0.02^{b}	0.34 ± 0.02^{a}	Nd
		5	6.63 ± 0.06^{b}	1.98 ± 0.06^{a}	0.73 ± 0.06^{c}	0.39 ± 0.05^{b}	Nd
		10	6.75 ± 0.04^{b}	1.99 ± 0.08^{a}	0.79 ± 0.07^{c}	0.44 ± 0.04^{b}	0.19 ± 0.02^{a}
VOB-2 (CNO + SFO)	80:20	0	4.21 ± 0.05^{a}	1.02 ± 0.03^{a}	0.48 ± 0.03^{a}	0.31 ± 0.02^{a}	Nd
		1	4.45 ± 0.03^{a}	2.03 ± 0.08^{b}	0.58 ± 0.02^{b}	0.35 ± 0.05^{a}	Nd
		5	4.66 ± 0.05^{a}	2.08 ± 0.06^{b}	0.62 ± 0.02^{b}	0.44 ± 0.04^{b}	Nd
		10	4.72 ± 0.04^{a}	2.10 ± 0.11^{b}	0.65 ± 0.05^{b}	0.47 ± 0.07^{b}	0.18 ± 0.03^{a}
VOB-3 (CNO + SBO)	80:20	0	4.54 ± 0.02^{a}	2.20 ± 0.08^{b}	0.55 ± 0.03^{b}	0.29 ± 0.02^{a}	Nd
		1	5.48 ± 0.06^{a}	2.36 ± 0.06^{b}	0.53 ± 0.02^{b}	0.35 ± 0.05^{a}	Nd
		5	5.48 ± 0.03^{a}	2.37 ± 0.08^{b}	0.63 ± 0.05^{b}	0.36 ± 0.04^{a}	Nd
		10	5.57 ± 0.07^{a}	2.39 ± 0.05^{b}	0.70 ± 0.05^{c}	0.44 ± 0.04^{b}	0.30 ± 0.01^{b}
VOB-4 (CNO + CSO)	80:20	0	8.31 ± 0.05^{c}	2.34 ± 0.07^{b}	0.40 ± 0.03^{a}	0.26 ± 0.05^{a}	Nd
		1	9.14 ± 0.05^{d}	2.46 ± 0.08^{b}	0.43 ± 0.04^{a}	0.31 ± 0.03^{a}	Nd
		5	9.54 ± 0.05^{d}	2.49 ± 0.09^{b}	0.55 ± 0.02^{b}	0.34 ± 0.04^{a}	Nd
		10	9.91 ± 0.05^{d}	2.47 ± 0.03^{b}	0.61 ± 0.05^{b}	0.38 ± 0.05^{a}	0.18 ± 0.03^{a}
VOB-5 (CNO + RBO + CSO)	60:20:20	0	8.29 ± 0.04^{c}	2.18 ± 0.06^{b}	0.59 ± 0.02^{b}	Nd	Nd
		1	9.80 ± 0.06^{d}	2.23 ± 0.06^{b}	0.67 ± 0.05^{b}	Nd	Nd
		5	10.64 ± 0.04^{d}	2.35 ± 0.03^{b}	0.72 ± 0.07^{c}	0.37 ± 0.02^{a}	0.17 ± 0.03^{a}
		10	11.28 ± 0.05^{e}	2.49 ± 0.04^{b}	0.76 ± 0.06^{c}	0.38 ± 0.05^{a}	0.27 ± 0.04^{b}
VOB-6 (CNO + RBO + SFO)	60:20:20	0	6.39 ± 0.07^{b}	2.22 ± 0.09^{b}	0.68 ± 0.05^{b}	Nd	Nd
		1	6.41 ± 0.05^{b}	2.27 ± 0.06^{b}	0.67 ± 0.02^{b}	Nd	Nd
		5	6.74 ± 0.06^{b}	2.30 ± 0.09^{b}	0.68 ± 0.05^{b}	0.51 ± 0.03^{c}	Nd
		10	9.45 ± 0.04^{d}	2.34 ± 0.07^{b}	0.70 ± 0.02^{c}	0.52 ± 0.07^{c}	0.29 ± 0.04^{b}
VOB-7 (CNO + RBO + SBO)	60:20:20	0	7.61 ± 0.05^{c}	2.64 ± 0.07^{b}	0.67 ± 0.05^{b}	Nd	Nd
		1	7.63 ± 0.03^{c}	2.66 ± 0.04^{b}	0.75 ± 0.06^{c}	Nd	Nd
		5	7.71 ± 0.06^{c}	2.71 ± 0.08^{b}	0.79 ± 0.09^{c}	0.51 ± 0.03^{c}	0.51 ± 0.05^{d}
		10	10.12 ± 0.04^{d}	2.89 ± 0.08^{b}	0.82 ± 0.07^{d}	0.54 ± 0.04^{c}	0.54 ± 0.07^{d}
VOB-8 (CNO + RBO + CSO)	50:30:20	0	11.79 ± 0.05^{e}	2.11 ± 0.08^{b}	0.63 ± 0.02^{b}	Nd	Nd
		1	12.10 ± 0.04^{e}	2.24 ± 0.06^{b}	0.64 ± 0.05^{b}	Nd	Nd
		5	12.20 ± 0.07^{e}	2.25 ± 0.08^{b}	0.74 ± 0.06^{c}	Nd	Nd
		10	12.24 ± 0.04^{e}	2.37 ± 0.08^{b}	0.83 ± 0.07^{d}	0.73 ± 0.07^{d}	Nd
VOB-9 (CNO + RBO + SFO)	50:30:20	0	7.84 ± 0.05^{c}	1.57 ± 0.08^{a}	0.76 ± 0.09^{c}	Nd	Nd
		1	8.22 ± 0.04^{c}	2.29 ± 0.01^{b}	0.76 ± 0.06^{c}	0.61 ± 0.04^{d}	Nd
		5	8.46 ± 0.05^{c}	2.35 ± 0.07^{b}	0.82 ± 0.07^{d}	0.67 ± 0.07^{d}	0.37 ± 0.05^{c}
		10	9.25 ± 0.07^{d}	2.33 ± 0.08^{b}	0.97 ± 0.09^{e}	0.73 ± 0.09^{d}	0.45 ± 0.05^{d}
VOB-10 (CNO + RBO + SBO)	50:30:20	0	8.01 ± 0.05^{c}	2.28 ± 0.06^{b}	0.58 ± 0.04^{b}	0.81 ± 0.07^{e}	Nd
		1	9.27 ± 0.04^{d}	2.36 ± 0.07^{b}	0.61 ± 0.02^{b}	0.87 ± 0.09^{e}	Nd
		5	9.41 ± 0.05^{d}	2.39 ± 0.08^{b}	0.67 ± 0.05^{b}	0.90 ± 0.07^{e}	0.22 ± 0.04^{b}
		10	9.81 ± 0.05^{d}	2.45 ± 0.05^{b}	0.76 ± 0.06^{c}	0.98 ± 0.09^{e}	0.03 ± 0.02^{a}

Note: Values within the column with different alphabets are significantly different ($p \leq .05$).

Abbreviations: AI, atherogenic index; CNO, canola oil; CSO, cotton seed oil; FC, frying cycle; MUFAs, monounsaturated fatty acids; Nd, not detected; PUFAs, polyunsaturated fatty acids; RBO, rice bran oil; SBO, soybean oil; SFO, sunflower oil; SFAs, saturated fatty acids; TI, thrombogenic index; UFAs, unsaturated fatty acids; VOBs, vegetable oil blends; ω6/ω3, linoleic/linolenic acid ratio.

C18:1n9c (Oleic)	C20:1n11 (Gadoleic)	C18:2n6c (Linoleic)	C18:3n3c (Linolenic)	SFAs	MUFAs	PUFAs	UFAs	ω6/ω3 ratio	AI	TI
60.92 ± 0.04^{d}	1.09 ± 0.03^{b}	23.20 ± 0.06^{b}	7.23 ± 0.06^{e}	7.85	62.01	30.43	92.44	3.21	0.05	0.11
59.70 ± 0.03^{c}	1.14 ± 0.03^{b}	22.83 ± 0.09^{c}	6.63 ± 0.08^{d}	9.36	60.84	29.46	90.30	3.44	0.07	0.14
59.17 ± 0.07^{c}	1.25 ± 0.04^{b}	22.49 ± 0.09^{a}	6.36 ± 0.09^{d}	9.73	60.42	28.85	89.27	3.54	0.07	0.14
59.08 ± 0.06^{c}	1.38 ± 0.02^{b}	22.70 ± 0.05^{b}	5.00 ± 0.07^{c}	10.16	60.46	27.70	88.16	4.54	0.08	0.15
61.28 ± 0.06^{d}	1.03 ± 0.08^{b}	26.93 ± 0.09^{c}	6.22 ± 0.09^{d}	6.02	62.31	33.15	95.46	4.33	0.04	0.08
59.26 ± 0.04^{c}	1.15 ± 0.02^{b}	26.68 ± 0.06^{b}	5.18 ± 0.08^{c}	7.41	60.41	31.86	92.27	5.15	0.05	0.11
58.25 ± 0.03^{c}	1.19 ± 0.07^{b}	26.27 ± 0.05^{b}	4.88 ± 0.08^{b}	7.80	59.44	31.15	90.59	5.38	0.05	0.12
58.01 ± 0.07^{c}	1.25 ± 0.04^{b}	24.93 ± 0.09^{c}	4.60 ± 0.07^{b}	8.12	59.26	29.53	88.79	5.42	0.05	0.12
57.44 ± 0.05^{c}	1.07 ± 0.02^{b}	28.89 ± 0.09^{6c}	5.69 ± 0.07^{c}	7.58	58.51	34.58	93.09	5.08	0.05	0.11
56.11 ± 0.06^{c}	1.08 ± 0.08^{b}	28.21 ± 0.06 ^{b}	5.48 ± 0.08^{c}	8.72	57.19	33.69	90.00	5.15	0.06	0.13
55.92 ± 0.03^{c}	1.26 ± 0.14^{b}	27.45 ± 0.09^{c}	5.30 ± 0.09^{c}	8.84	57.18	32.75	89.93	5.18	0.06	0.13
55.31 ± 0.06^{c}	1.32 ± 0.03^{b}	26.81 ± 0.05 ^{b}	5.10 ± 0.07^{c}	9.40	56.63	31.91	88.54	5.26	0.06	0.14
50.47 ± 0.06^{b}	0.79 ± 0.02^{a}	31.43 ± 0.09 ^{c}	5.95 ± 0.08^{c}	11.31	51.26	37.38	88.64	5.28	0.09	0.18
49.85 ± 0.09^{a}	0.84 ± 0.04^{a}	31.13 ± 0.09^{c}	4.72 ± 0.06^{b}	12.34	50.69	35.85	86.54	6.59	0.11	0.21
49.59 ± 0.02^{a}	0.95 ± 0.03^{a}	30.37 ± 0.05^{b}	4.60 ± 0.07^{b}	12.92	50.54	34.97	85.51	6.60	0.11	0.22
49.06 ± 0.04^{a}	1.01 ± 0.02^{b}	30.34 ± 0.06^{b}	4.34 ± 0.09^{b}	13.55	50.07	34.68	84.75	6.99	0.12	0.23
51.69 ± 0.05^{b}	1.08 ± 0.08^{b}	30.54 ± 0.05^{b}	6.01 ± 0.08^{d}	11.06	52.77	36.55	89.32	5.08	0.09	0.17
50.58 ± 0.06^{b}	1.06 ± 0.07^{b}	28.65 ± 0.09^{c}	5.00 ± 0.09^{c}	12.70	51.64	33.65	85.29	5.73	0.11	0.22
50.50 ± 0.07^{b}	1.00 ± 0.04^{b}	28.36 ± 0.09^{c}	4.80 ± 0.07^{b}	14.25	51.50	33.16	84.66	5.91	0.13	0.24
48.66 ± 0.55^{a}	0.98 ± 0.02^{a}	28.31 ± 0.09^{c}	4.36 ± 0.06^{b}	15.18	49.64	32.67	82.31	6.49	0.14	0.26
52.32 ± 0.05^{b}	0.71 ± 0.02^{a}	29.75 ± 0.06 ^{b}	5.16 ± 0.06^{c}	9.29	53.03	34.91	87.94	5.76	0.07	0.15
56.21 ± 0.06^{c}	0.93 ± 0.07^{a}	28.65 ± 0.09 ^{c}	5.02 ± 0.07^{c}	9.35	57.14	33.67	90.81	5.70	0.07	0.15
55.2 ± 0.07^{c}	1.07 ± 0.08^{b}	28.52 ± 0.05^{b}	4.89 ± 0.08^{b}	10.23	56.27	33.41	89.68	5.83	0.08	0.16
54.71 ± 0.03^{b}	1.11 ± 0.22^{b}	28.46 ± 0.09 ^{c}	4.19 ± 0.08^{b}	13.30	55.82	32.65	88.47	6.79	0.11	0.22
53.23 ± 0.07^{b}	0.71 ± 0.02^{a}	30.83 ± 0.05^{b}	5.96 ± 0.06^{c}	10.92	53.94	36.79	90.73	5.17	0.08	0.17
52.44 ± 0.06^{b}	0.97 ± 0.03^{a}	30.16 ± 0.09 ^{c}	5.90 ± 0.09^{c}	11.04	53.41	36.06	89.47	5.11	0.09	0.17
51.93 ± 0.07^{b}	1.21 ± 0.07^{b}	29.80 ± 0.09^{c}	5.78 ± 0.08^{c}	12.23	53.14	35.58	88.72	5.15	0.09	0.18
46.38 ± 0.06^{a}	1.23 ± 0.08^{b}	28.41 ± 0.06^{b}	5.60 ± 0.08^{c}	14.91	47.61	34.01	81.62	5.07	0.12	0.24
50.19 ± 0.01^{b}	0.92 ± 0.02^{a}	30.18 ± 0.05^{b}	4.91 ± 0.06^{b}	14.53	51.11	35.09	86.20	6.15	0.14	0.25
49.95 ± 0.05^{a}	0.96 ± 0.04^{a}	29.96 ± 0.09^{c}	4.85 ± 0.08^{b}	14.98	50.91	34.81	85.72	6.18	0.14	0.26
49.96 ± 0.06^{a}	1.07 ± 0.02^{b}	29.88 ± 0.09^{c}	4.25 ± 0.08^{b}	15.19	51.03	34.13	85.16	7.03	0.14	0.27
49.50 ± 0.04^{a}	1.16 ± 0.19^{b}	29.25 ± 0.06^{b}	4.01 ± 0.09^{b}	16.17	50.66	33.26	83.92	7.29	0.15	0.28
54.46 ± 0.05^{b}	0.76 ± 0.02^{a}	28.34 ± 0.09^{c}	6.25 ± 0.08^{d}	10.17	55.22	34.59	89.81	4.53	0.09	0.16
54.10 ± 0.05^{b}	0.95 ± 0.02^{a}	29.64 ± 0.05^{c}	4.39 ± 0.07^{b}	11.88	55.05	34.03	89.08	6.75	0.09	0.19
53.33 ± 0.05^{b}	1.11 ± 0.22^{b}	30.41 ± 0.09^{c}	3.41 ± 0.09^{a}	12.67	54.44	33.82	88.26	8.91	0.10	0.21
52.08 ± 0.04^{b}	1.27 ± 0.03^{b}	22.21 ± 0.06^{b}	3.22 ± 0.06^{a}	13.73	53.35	25.43	78.78	6.89	0.12	0.24
53.25 ± 0.03^{b}	0.81 ± 0.02^{a}	29.29 ± 0.03^{a}	5.76 ± 0.08^{c}	11.68	54.06	35.05	89.11	5.08	0.09	0.17
51.02 ± 0.05^{b}	0.87 ± 0.04^{a}	29.76 ± 0.09^{c}	4.59 ± 0.09^{b}	13.11	51.89	34.35	86.24	6.48	0.11	0.21
50.74 ± 0.05^{b}	0.90 ± 0.02^{a}	29.66 ± 0.09^{c}	4.10 ± 0.08^{b}	13.59	51.64	33.76	85.40	7.23	0.11	0.22
50.08 ± 0.07^{b}	0.98 ± 0.09^{a}	27.95 ± 0.05^{b}	3.62 ± 0.07^{a}	14.03	51.06	31.57	82.63	7.72	0.12	0.24

TABLE 3 Pearson correlation of various properties of vegetable oil blends after frying cycles

	FCs	AV	PV	p-AV	Viscosity	OU	SFAs	MUFAs	UFAs
AV	0.667**								
PV	0.610**	0.342*							
p-AV	0.744**	0.648**							
OSI	−0.797**	−0.529**	−0.736**	−0.438**					
Viscosity	0.563**	0.689**		0.745**					
OU	0.841**				0.517**				
SFAs	0.391*	0.576**		0.522**	0.718**	0.409*			
PUFAs						-0.423**			
UFAs	−0.579**	−0.626**		−0.589**	−0.663 **		−0.856**		
ω6/ω3							0.679**		
AI		0.504**		0.439**			0.976**	−0.856**	−0.819**
TI		0.593**		0.501**			0.989**	−0.862**	−0.859**
3009 cm^{-1}	⁻0.659**						−0.385*		0.526**
2955 cm^{-1}	0.625**								−0.316*
2925 cm^{-1}	0.520**								−0.315*
2854 cm^{-1}	0.514**								
1745 cm^{-1}	0.424*	0.351*	0.307*						
1650 cm^{-1}	−0.543**	−0.687**	−0.458**	−0.417*					

Abbreviations: AI, atherogenic index; AV, acid value; FC, frying cycle; MUFAs , monounsaturated fatty acids; OSI, oxidative stability index, OU, oil uptake, p-AV, p-anisidine value; PUFAs, polyunsaturated fatty acids; PV, peroxide value; SFAs, saturated fatty acids; TI, thrombogenic index; UFAs, unsaturated fatty acids; ω6/ω3, linoleic/linolenic acid ratio.

*$p < .05$; **$p < .005$.

(Kaur et al., 2020; Zribi et al., 2014). The p-AV showed a higher significant ($p \leq .005$) variation with FCs than the VOBs (Table S1). *F* values revealed higher significant effect of FCs on p-AV than the VOBs ($p \leq .005$, Table S1). After first, fifth, and tenth FCs, p-AV of VOBs ranged from 0.45 to 3.11, 0.59 to 3.65, and 2.26 to 4.47, respectively. A minor change in p-AV (0.45 to 0.59) with an increment from first to fifth FC was observed in VOB-4 while a significant change (1.78 to 3.22) was noticed in VOB-8. The lowest and highest p-AV after the tenth FC was noted for VOB-3 and VOB-9, respectively. The high p-AV of VOB-9 (4.47) after tenth FC indicates extensive degradation of oxidized UFAs (Table 2). The previous studies had correlated the production of nonvolatile aldehydes in oils during frying process with the level of UFAs as they are more liable to oxidative degradation (Multari et al., 2019; Zribi et al., 2014). Liu et al. (2019) also observed a similar change in p-AV by increasing frying time from 0 to 40 hr in two vegetable oils (Palm oil and SFO). Similar increase in p-AV of oils with frying process was reported in previous studies (Kaur et al., 2020; Song et al., 2017; Zribi et al., 2014). However, the p-AV observed for all fresh VOBs and after FCs was less than the recommended value of 10 for oils (Kaur et al., 2020). The p-AV exhibited positive significant ($p \leq .05$) correlation with FCs ($r = 0.744$) and AV ($r = 0.648$), while highly negative significant ($p \leq .005$) correlation with UFAs ($r = -0.589$) as given in Table 3. Similar positive correlation of p-AV with FCs and FFAs of vegetable oils was reported by Kaur et al. (2020).

3.4 | Effect of FCs on OSI of VOBs

OSI determines the relative resistance of oil to oxidation as it measures lipid oxidation and predict the shelf-life of oils (Suri et al., 2019). The OSI of VOBs (fresh and after first, fifth, and tenth FCs) are listed in Table 1. OSI of fresh VOBs ranged between 4.63 and 7.93 hr, with the lowest and highest in VOB-10 and VOB-7, respectively. It depends on the antioxidant compounds and FAC of the oils (Kaur et al., 2019). OSI decreased with increment in FCs indicating the formation of lipid oxidation products in VOBs during intermittent frying process. OSI exhibited higher significant variation with FCs than the VOBs ($p \leq .005$, Table S1). After first, fifth, and tenth FCs, OSI of VOBs ranged from 4.31 to 7.84, 1.72 to 4.05, and 1.14 to 3.55 hr, respectively. VOB-7 showed the highest OSI after first, fifth, and tenth FC while VOB-4 exhibited the lowest OSI after fifth and tenth FC. Zribi et al. (2014) reported significant decrease in OSI of corn oil, olive oil, SFO and SBO following five deep-frying sessions. Another study reported similar change in OSI of SBO with the prolongation of frying time (Liu et al., 2018). A similar decrease in OSI of five different refined vegetable oils was reported by Kaur et al. (2020) with the addition of FCs during intermittent frying process. The decrease in OSI with the addition of FCs was higher in VOB-4 and lower in VOB-7 (Table 1) and this might be due to the difference in the proportion of MUFAs of oils (Kaur et al., 2020; Zribi et al., 2014). A highly significant ($p \leq .005$) negative correlation of OSI with FCs, PV, AV and p-AV ($r = -0.797$, -0.736, -0.529 and -0.438, respectively)

was observed (Table 3). The previous study on intermittent frying also reported similar correlation of OSI with FCs, p-AV, and PV of five different vegetable oils (Kaur et al., 2020).

3.5 | Effect of FCs on viscosity of VOBs

The viscosity of VOBs (fresh and after first, fifth, and tenth FCs) is given in Table 1. The viscosity of fresh VOBs varied from 55.02 to 62.67 mPa s, with lowest and highest in VOB-3 and VOB-5, respectively. The viscosity of VOBs relates with the arrangement of FAs (saturation/unsaturation and chain length) on the glycerol molecule (Hashempour-Baltork et al., 2016). The VOBs containing a higher amount of long-chain SFAs exhibited higher viscosities. Similar relation of FAs with viscosity was described in previous studies on fresh vegetable oils (Kaur et al., 2019, 2020). The viscosity of VOBs increased with the addition of FCs. Viscosity exhibited higher significant variation with FCs than the VOBs ($p \leq .005$, Table S1). After first, fifth, and tenth FCs, the viscosity of VOBs ranged from 59.41 to 64.95, 60.00 to 66.00, and 60.31 to 70.27 mPa s, respectively. The maximum and minimum change in viscosity from fresh to tenth FC was observed in VOB-10 (62.29 to 70.27 mPa s) and VOB-7 (60.29 to 62.94 mPa s), respectively. VOB-4 and VOB-7 had high PUFA contents and they exhibited low change in viscosity with an increment in FCs (Tables 1 and 2). The VOBs showing slow increase in viscosity with FCs are the stable oil blends for frying process (Hashempour-Baltork et al., 2016). The changes in the level of PUFAs, SFAs, and primary and secondary oxidation products contribute in changing the viscosity of frying oil (Hashempour-Baltork et al., 2016; Kaur et al., 2020). The study conducted by Ramadan et al. (2006) on two VOBs (SFO + palm olein and CSO + palm olein) reported increase in viscosity during intermittent frying for two consecutive days. Similar change in viscosity of five vegetable oils with the addition of FCs was reported by Kaur et al. (2020). Viscosity exhibited highly positive significant ($p \leq .005$) correlation with SFAs ($r = 0.718$) and FCs ($r = 0.563$) while negative correlation with UFAs ($r = -0.633$) as given in Table 3. Moreover, a highly significant ($p \leq .005$) positive correlation of viscosity with p-AV and AV ($r = 0.745$ and 0.689, respectively) was also observed.

3.6 | Effect of FCs on oil uptake

The low oil uptake (OU) in fried food is preferred by consumers for good health (Waghmare et al., 2018). During frying of the chickpea splits in VOBs, the OU significantly increased with the addition of FCs. The OU during first, fifth, and tenth FCs ranged from 5.0% to 17.0%, 9.0% to 23.2%, and 13.7% to 32.0%, respectively (Table 1). The lowest OU was observed in VOB-7 and VOB-3 during first and fifth FC, respectively. While among all of the VOBs, the lowest change in OU from first to tenth FC was observed in VOB-3 (6.0% to 13.70%). The highest OU during first, fifth, and tenth FCs was observed in VOB-8. *F* values revealed that VOBs showed higher significant effect on OU than the FCs ($p \leq .005$, Table S1). The increase in OU might be related to the changes in viscosity and FAC of VOBs with increment in FCs. Due to high viscosity more oil accumulates on the surface of the fried food and penetrate during cooling process (Dana & Saguy, 2006; Debnath et al., 2012). The previous studies on intermittent frying using RBO (Debnath et al., 2012) and five different vegetable oils (Kaur et al., 2020) reported significant increase in OU with the addition of FCs. As given in Table 3, OU showed highly positive significant ($p \leq .005$) correlation with FCs and viscosity ($r = 0.841$ and 0.517, respectively), positive significant ($p \leq .05$) correlation with SFAs ($r = 0.409$), and highly negative significant ($p \leq .005$) correlation with PUFAs ($r = -0.423$). Similar correlation of OU with viscosity, FCs, and PUFAs was reported using five different refined vegetable oils (Kaur et al., 2020).

3.7 | Effect of FCs on FAC of VOBs

The FAs profile of VOBs (fresh and after first, fifth and tenth FCs) is given in Table 2. The main FAs detected in fresh VOBs were oleic (50.19%–61.28%), linoleic (23.20%–31.43%), linolenic (4.91%–7.23%), palmitic (4.21%–11.79%), and stearic (1.02%–2.64%) acids. The FAs detected in trace amounts in fresh VOBs include gadoleic (0.71%–1.09%) and arachidic (0.40%–0.76%) acids. Behenic (0.26%–0.81%) acid was detected in four fresh blends of two oils (VOB-1 to VOB-4) and in VOB-10 while lignoceric acid (C24:0) was not detected in all fresh VOBs. In fresh VOBs, the sum of MUFAs, PUFAs, and SFAs accounted for 51.11%–62.31%, 30.43%–37.38%, and 6.02%–14.53%, respectively. The highest total MUFAs, PUFAs, and SFAs contents were observed in VOB-2, VOB-4, and VOB-8, respectively. The predominant MUFAs, PUFAs, and SFAs in VOBs were oleic, linoleic, and palmitic acids, respectively. The major differences in the content of FAs of VOBs were related with the variation in the levels of oleic, linoleic (ω-3), and linolenic (ω-6) acids. VOB-4 and VOB-1 had the highest proportion of ω-3 and ω-6 FAs, respectively. The ω-3 and ω-6 FAs are essential that must be provided in the diet for human health and well-being (Kaur et al., 2019; Saini & Keum, 2018). Most of the fresh VOBs (VOB-3 to VOB-8 and VOB-10) had a ω6/ω3 ratio within the acceptable limits of 5–10:1 recommended by FAO/WHO (2009). The other fresh VOBs (VOB-1, VOB-2, and VOB-9) had a ratio of ω6/ω3 less than the lower limit (Table 2). Blending of vegetable oils is considered as an efficient method to get a balanced FAC and desired ω6/ω3 ratio in oil mixtures for health benefits (Hashempour-Baltork et al., 2016).

Changes in the FAC of VOBs were noticed with the addition of FCs during the deep-frying process. A slight increment in SFAs and decline in MUFAs and PUFAs were observed in VOBs following increment in FCs. Similar results were reported in previous studies on frying in refined vegetable oils (Kaur et al., 2020) and VOBs (Ramadan et al., 2006). The level of palmitic, stearic, arachidic, and behenic acids was slightly increased, while the level of oleic, linoleic, and linolenic acids was decreased from first to tenth FCs. Ramadan et al. (2006) also observed similar changes in FAs during frying in two

different VOBs for 2 consecutive days. However, a slight increase in oleic acid level was observed in VOB-6 after first FC, which might be due to the breakdown of PUFAs into oleic acid during the frying process. Aniołowska and Kita (2016) also reported increase in the level of oleic acid during frying of potato chips in palm oil after first FC. The changes in FAC during the frying process might be due to the degradation of FAs containing two or three bonds as they are more prone to thermal and oxidative degradation (Debnath et al., 2012; Kaur et al., 2020). VOB-5 and VOB-9 exhibited higher changes in the level of total SFAs and UFAs, respectively with an increment in FCs (Table 2). While VOB-7, VOB-8, and VOB-6 showed the lowest change from zero to tenth FC in ω6/ω3 ratio, SFAs and UFAs contents, respectively. The decrease in the level of UFAs during frying process correlates with the increase in SFAs content in VOBs. Similar results were reported in studies on frying in different oils (Debnath et al., 2012; Kaur et al., 2020; Multari et al., 2019; Ramadan et al., 2006; Zribi et al., 2014). PUFAs and UFAs varied significantly with FCs, while SFAs, MUFAs and ω6/ω3 ratio varied significantly among VOBs (p <.005, Table S1). The SFAs showed positive significant ($p \leq .05$) correlation with FCs ($r = 0.391$) and highly positive significant correlation ($p \leq .005$) with viscosity, ω6/ω3 ratio, AV, and p-AV ($r = 0.718$, 0.679, 0.576, and 0.522, respectively) as given in Table 3. While a highly significant ($p \leq .005$) negative correlation of UFAs with FCs, p-AV, AV, viscosity, and SFAs ($r = -0.579$, −0.589, −0.626, −0.663 and −0.856, respectively, $p \leq .005$) was observed (Table 3). Similar negative correlation of UFAs with FCs, FFA, viscosity, and p-AV of five different vegetable oils was reported in previous study on intermittent frying (Kaur et al., 2020).

3.8 | Effect of FCs on TI and AI of VOBs

The TI and AI of VOBs (fresh and after first, fifth, and tenth FCs) are listed in Table 1. The TI and AI are two dietary lipid indices considered to realize the effect of SFAs and UFAs in the occurrence of cardiovascular problems (Kaur et al., 2020; Pereira et al., 2019). The SFAs with a chain length of C12-C16 are considered as atherogenic as they play a major role in raising blood cholesterol level, whereas SFAs with a chain length of C14-C18 are thrombogenic due to their role in clot formation and clogging of blood vessels. While UFAs contribute to minimizing the thrombogenicity and atherogenicity of oils (Kaur et al., 2020; Mohanty et al., 2012; Pereira et al., 2019). AI and TI of fresh VOBs ranged between 0.04 and 0.14 and 0.08 and 0.25, respectively. The lowest AI and TI were observed for fresh VOB-2 and the highest for VOB-8. The VOBs rich in UFAs (VOB-1, VOB-2, and VOB-3) exhibited low TI and AI compared with other VOBs. A slight increase in TI and AI of VOBs was observed with an increment in FCs. After first, fifth, and tenth FCs, the minimum and the maximum values of two indices were observed for VOB-2 and VOB-8, respectively. VOB-5 showed the maximum change in values for both indices with an increment from first to tenth FC. TI and AI exhibited higher significant effect among VOBs than the FCs ($p \leq .005$,

TABLE 4 Principal components for illustrating the interpretation in Figure 2

Variable	PC1	PC2	PC3	PC4	PC5
FCs	−0.273	−0.250	0.105	−0.072	−0.036
AV	−0.288	−0.085	−0.010	−0.106	0.025
PV	−0.117	−0.320	0.488	0.270	0.068
P-AV	−0.267	−0.106	−0.335	−0.155	−0.102
OSI	−0.442	0.270	−0.292	−0.277	−0.168
VISCOSITY	−0.286	0.052	−0.332	−0.122	−0.081
OU	−0.274	−0.214	0.024	−0.216	0.115
SFAs	−0.285	0.273	−0.010	0.014	0.013
MUFAs	0.217	−0.353	−0.201	−0.138	−0.071
PUFAs	0.059	0.408	0.278	0.226	0.118
UFAs	0.302	−0.125	−0.038	0.000	0.001
ω6/ω3	−0.246	0.152	0.043	0.275	−0.193
AI	−0.262	0.310	−0.004	−0.026	−0.029
TI	−0.286	0.273	0.016	0.015	−0.058
3,009	0.246	0.161	0.218	−0.133	−0.255
1745	−0.119	−0.091	0.455	−0.461	−0.588
1,650	0.212	0.221	0.033	−0.032	−0.125
1,417	0.041	0.193	0.257	−0.609	0.598

Note: PC1-PC5 are the first-five principal components.

Abbreviations: AI, atherogenic index; AV, acid value; FCs, frying cycles; MUFAs, monounsaturated fatty acids; OSI, oxidative stability index; p-AV, p-anisidine value; PV, peroxide value; PUFAs, polyunsaturated fatty acids; SFAs, saturated fatty acids; TI, thrombogenic index; UFAs, unsaturated fatty acids; ω6/ ω3, Linoleic/linolenic acid ratio.

Table S1). The increase in TI and AI correspond with the changes in SFAs and UFAs contents of VOBs during the deep-frying process. Similar changes in TI and AI were reported by Kaur et al. (2020) while deep-frying in five different vegetable oils. A highly significant ($p \leq .005$) positive correlation of AI and TI with SFAs ($r = 0.976$ and 0.989, respectively), AV ($r = 0.504$ and 0.593, respectively), and p-AV ($r = 0.439$ and 0.501, respectively) was observed (Table 4). While a highly significant ($p \leq .005$) negative correlation of AI and TI with MUFAs ($r = -0.856$ and −0.862, respectively) and UFAs ($r = -0.819$ and −0.859, respectively) was observed (Table 4). AI and TI was positively correlated with FFA and negatively correlated with PUFAs during intermittent frying in five vegetable oils as reported by Kaur et al. (2020).

3.9 | Effect of FCs on FTIR spectra of VOBs

The FTIR spectra of fresh VOBs and after first, fifth, and tenth FC are given in Figure 1(a–j). The two major spectral informative regions (2,800–3,100 and 700–1,800 cm^{-1}) display characteristic peaks at specific wavenumber (cm^{-1}) that can be assigned to specific functional groups of FAs (Kaur et al., 2020; Suri et al., 2022). The peaks observed at 3,009, 2,955, 2,925, and 2,854 cm^{-1} of first informative region and peaks at 1,745, 1,650, 1,417, 1,377, 1,238, 1,157, and 725 cm^{-1} of second informative region are shown in FTIR spectra of oils. The effect of FCs on the quality of VOBs was evaluated using FTIR spectra. The fresh VOBs and those collected after first, fifth and tenth FC showed identical signal patterns attributed to the functional groups of triglycerides. However, the intensities of peaks at 3,009, 2,925, 1,745, 1,650, 1,417, 1,157, and 968 cm^{-1}showed minor variations with increment in FCs. The small peak at 3,009 cm^{-1} (stretching symmetric vibration of the cis-olefinic groups of UFAs) was observed in all fresh VOBs with the highest intensity in VOB-1 and VOB-2. The intensity of peak at 3,009 cm^{-1} showed minor variation in VOBs after first FC while after fifth and tenth FC, a gradual decrease was observed. VOB-2 and VOB-3 showed the least change while VOB-9 showed a maximum decline in peak intensity after the tenth FC. The changes observed in intensity of peak at 3,009 cm^{-1} relates with the disappearance of cis-olefinic groups present in UFAs of oil (Suri et al., 2020). As shown in the FAC of VOBs (Table 2), the maximum decline in the level of total UFAs from first to tenth FC was also observed in VOB-9 (89.81 to 78.78%). The peak at 3,009 cm^{-1} exhibited highly significant ($p \leq .005$) positive correlation with UFAs ($r = 0.526$) and negative correlation with FCs ($r = -0.659$) as given in

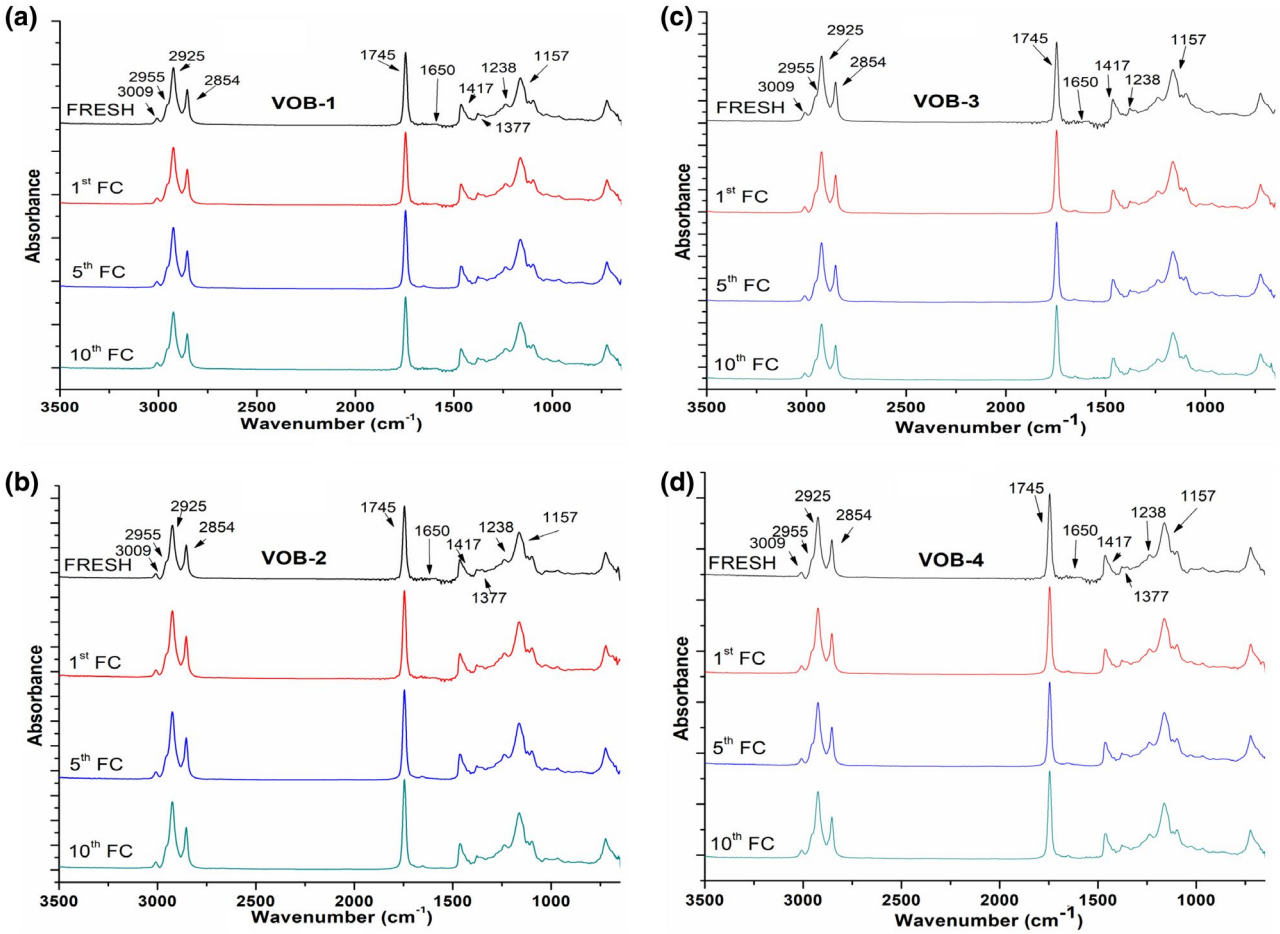

FIGURE 1 FTIR spectra of fresh vegetable oil blends and after first, fifth and tenth FCs (a) VOB-1, (b) VOB-2, (c). VOB-3, (d) VOB-4, (e) VOB-5, (f) VOB-6, (g) VOB-7, (h) VOB-8, (i) VOB-9 and (j) VOB-10

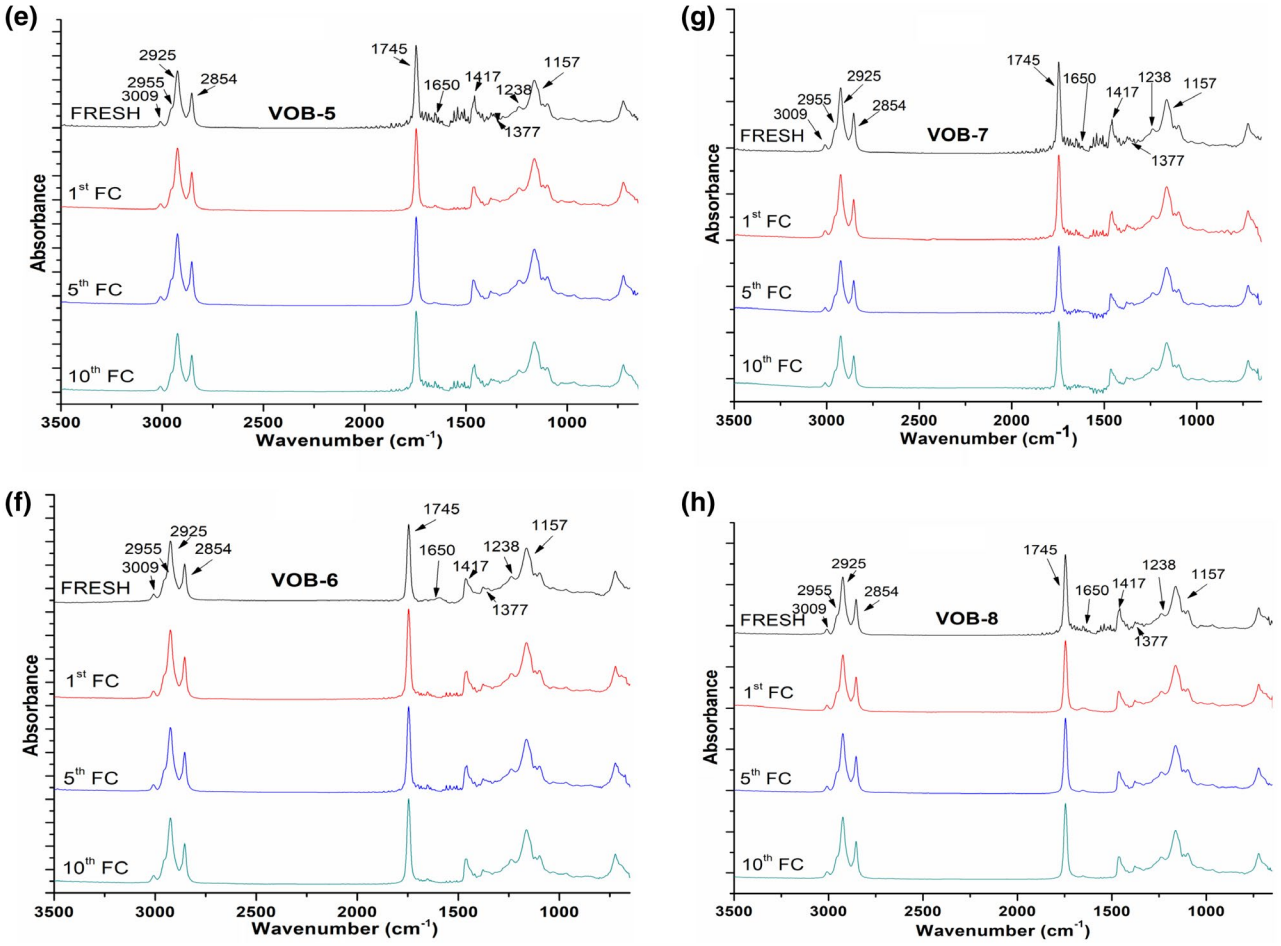

FIGURE 1 (Continued)

Table 3. A significant ($p \leq .05$) negative correlation of this peak with SFAs ($r = -0.385$) was also observed. The previous study had related variation in intensity of this peak with changes in the level of UFAs in five vegetable oils during intermittent FCs (Kaur et al., 2020).

The peaks detected at 2,955, 2,925, and 2,854 cm^{-1} representing CH stretching vibration of aliphatic CH_3 and CH_2 groups exhibited slight increase in intensities with the addition of FCs in all VOBs (Figure 1). These three peaks have been correlated with the SFAs content in oils (Kaur et al., 2020; Suri et al., 2020). The minimal change in intensities of these three peaks was noted in VOB-3 and VOB-8, while the maximal change was observed in VOB-5 and VOB-9 after the tenth FC. The level of total SFAs also showed the least change in VOB-3 (7.58% to 9.40%) and VOB-8 (14.53% to 16.17%) from fresh to tenth FC (Table 2). These three peaks (2,955, 2,925, and 2,854 cm^{-1}) showed highly positive significant ($p \leq .005$) correlation with FCs ($r = 0.625, 0.520, 0.514$, respectively) as given in Table 3. Moreover, the peak at 2,955 and 2,925 cm^{-1} also exhibited significant ($p \leq .05$) negative correlation with UFAs ($r = -0.316$ and -0.315, respectively). The variation in intensities of peaks in the region of 2,800–3,100 cm^{-1} relates with increment in SFAs and decline in UFAs in oils with an increment in FCs (Kaur et al., 2020).

The sharp peaks recorded at 1,745 and 1,157 cm^{-1} (related to stretching vibrations of C = O and C–O ester groups, respectively) in VOBs showed minor variation with the addition of FCs. VOB-3 showed minimal change in intensities of peaks at 1,745 and 1,157 cm^{-1} after first, fifth, and tenth FC. VOB-1, VOB-7, and VOB-9 showed the maximal change in peak intensities at 1,745 and 1,157 cm^{-1} after the tenth FC (Figure 1). The decomposition of hydroperoxides into secondary products was also higher in these VOBs after the tenth FC as indicated by higher p-AV (Table 1). The intensity of peak at 1,745 cm^{-1} correlates with the development of secondary oxidation products following the deep-frying process in oils (Kaur et al., 2020; Srivastava & Semwal, 2015). A positive significant ($p \leq .05$) correlation of peak at 1,745 cm^{-1} with FCs, AV, and PV ($r = 0.424, 0.351, 0.307$, respectively, $p \leq .05$) was observed (Table 3).

The small peaks observed at 1,650 and 1,417 cm^{-1} (represents C = C stretching of *cis*-olefins and bending vibrations of CH bonds of *cis*-disubstituted olefins, respectively) showed a slight decline in intensities after fifth and tenth FCs in all VOBs. While small peak observed at 968 cm^{-1} (represents *trans*-HC=CH–out of plane bending vibrations) showed minor variation in intensity after first, fifth, and tenth FC in all VOBs. VOB-2 and VOB-9 showed minimal change in intensity of peak at 968 cm^{-1} with increment in FCs. The observed changes in intensities of small peaks at 1,650 and 968 cm^{-1} reflect the isomerization of *cis* FAs to trans FAs at the time of deep-frying

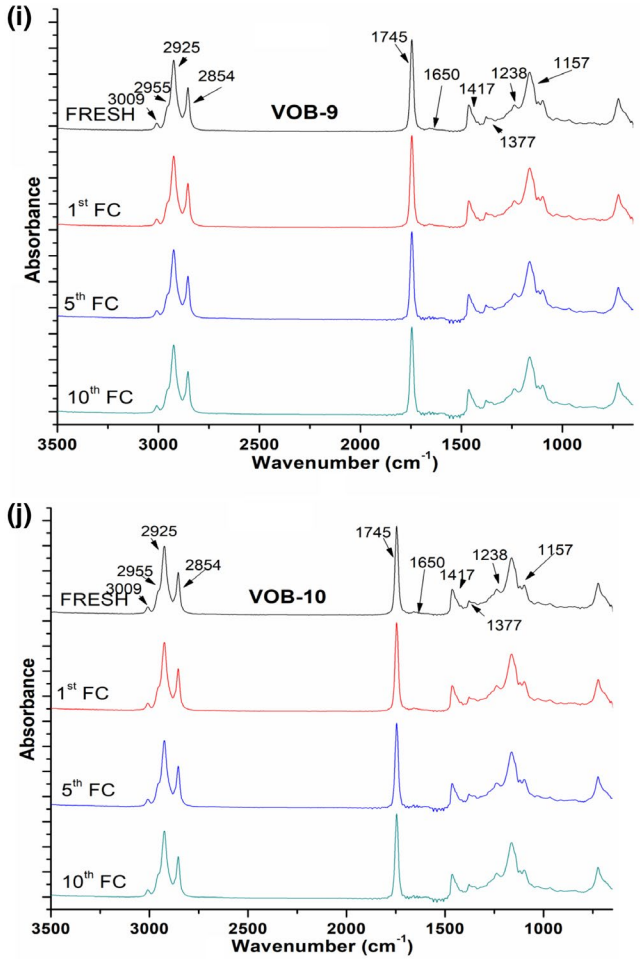

FIGURE 1 (Continued)

process (Siddique et al., 2015). The peaks observed at 1,377 cm^{-1} (bending vibration of CH_2 groups), 1,238 cm^{-1} (stretching vibration of C–O ester groups), and 725 cm^{-1} (overlapping of CH_2 bending vibration and out-of-plane vibration of *cis*-disubstituted olefins) also showed minor changes in intensities with the addition of FCs in comparison with fresh VOBs. All the peaks in FTIR spectra were observed at designated wavenumbers after first, fifth, and tenth FCs. A small peak at 1,650 cm^{-1} showed highly significant ($p \leq .005$) negative correlation with FCs, AV, PV ($r = -0.543$, -0.687, and -0.458, respectively). A significant ($p \leq .05$) negative correlation of peak at 1,650 cm^{-1} with p-AV ($r = -0.417$) was also observed (Table 3). The differences in peak intensities relates with the changes in the level of FAs and development of oxidative products during frying in VOBs. Similar changes in FAC and oxidation in frying oils and their correlation with intensities of peaks were described in other studies (Kaur et al., 2020; Srivastava & Semwal, 2015; Talpur et al., 2014).

3.10 | Principal component analysis (PCA)

To correlate VOBs (fresh and after FCs) on the basis of chemical properties, FAC, OU, viscosity, OSI and FTIR spectra and to establish relation among various quality and stability characteristics of VOBs, PCA was carried out (Figure 2 and Table 4). The first five principal components (PC) (Eigen value >1 considered) were found to account for 86% variability in the data set. The PC1, PC2, PC3, PC4, and PC5 individually accounted for 44%, 20%, 10%, 7%, and 5% variability, respectively. The variables that primarily attributed to building PC1 were OSI (−0.442), AV (−0.288), TI (−0.286), OU (−0.274), SFAs

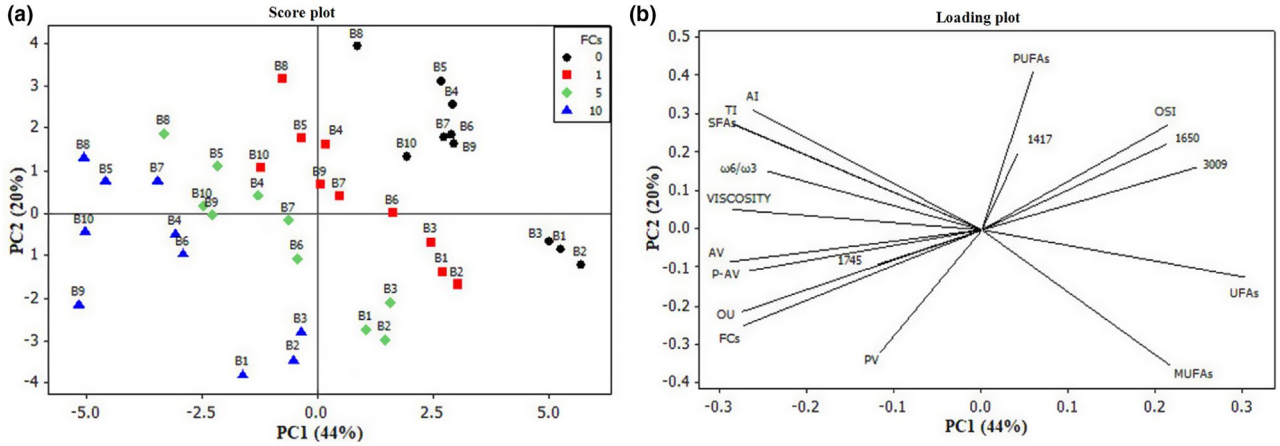

FIGURE 2 Principal component analysis: (a) score plot and (b) loading plot describing and comparing the relationship among different parameters of fresh vegetable oil blends and after first, fifth and tenth frying cycles (Where AI, atherogenic index; AV, acid value; B1 to B10: VOB-1-VOB-10; FCs, frying cycle; MUFAs, monounsaturated fatty acids; OSI, oxidative stability index; OU, oil uptake; p-AV, p-anisidine value; PUFAs, polyunsaturated fatty acids; PV, peroxide value; SFAs, saturated fatty acids; TI, thrombogenic index; UFAs, unsaturated fatty acids; ω6/ω3, linoleic/linolenic acid ratio)

(−0.285), UFAs (0.302), and FTIR peak at 3,009 cm^{-1} (0.246). The variability of PC2 was largely contributed by PV (−0.320), MUFAs (−0.353), PUFAs (0.408), AI (0.310) and peak at 1,650 cm^{-1} (0.221). The two-dimensional score plot (Figure 2a) between PC1 and PC2 clearly depicts the impact of FCs on quality and stability characteristics of VOBs. A gradual shift in the arrangement of VOBs can be seen in the score plot from zero to tenth FC with the progression of PC1 from positive to negative. The shift in the alignment of the colored ligands (zero, first, fifth, and tenth FCs) of VOBs in the score plot indicates that chemical properties (AV, PV and p-AV), OU, SFAs, ω6/ω3 ratio, AI and TI of VOBs increased while OSI and UFAs decreased with the addition of FCs. The higher change in viscosity, OU, and OSI was observed in VOB-10, VOB-8, and VOB-9, respectively, with an increment in FCs. Further, VOB-9 and VOB-10 also exhibited maximum change in p-AV after fifth and tenth FC. As indicated by the alignment of colored ligands, the changes in chemical properties, FAC, and OSI were lower in VOB-3 and VOB-7 compared with other VOBs. In a loading plot between PC1 and PC2 (Figure 2b), SFAs, AI, TI, ω6/ω3 ratio, and viscosity were positioned close to one another, indicating a close positive correlation between them. Further, OU, p-AV, and AV were in close relation with FCs, while the opposite relation of viscosity with UFAs and OSI with FCs was observed. The FTIR peaks at 3,009 and 1,650 cm^{-1} related positively with UFAs and negatively with viscosity and FCs. While, the another peak at 1,745 cm^{-1} related with secondary oxidative products (formation of carbonyl compounds) exhibited opposite relation with OSI and close relation with p-AV and FCs.

4 | CONCLUSION

The ten freshly prepared VOBs (from five different vegetable oils) showed significant difference in OSI, FAC, and ω6/ω3 ratio, AI, TI, and chemical properties. The deep-frying of chickpea splits for 10 discontinuous FCs exhibited changes in chemical properties, quality, and stability characteristics of VOBs. Among all blends, VOB-3 exhibited lower AV, p-AV, AI, TI, and the favorable ω6/ω3 ratio while VOB-7 showed higher OSI, lower PV, and viscosity compared with other VOBs. VOB-5 and VOB-9 exhibited a higher change in FAC, ω6:ω3 ratio, AI, TI, and FTIR spectra (peaks at 3,009, 2,925, 2,854, and 1,745 cm^{-1}) while minor variations were observed in VOB-3 and VOB-7. Based on the results, our study concludes that VOB-3 and VOB-7 were least susceptible to quality degradation during intermittent frying of chickpea splits.

ACKNOWLEDGMENTS

Amritpal Kaur acknowledges Indo-US Science and Technology Forum (IUSSTF) for providing financial support under Indo-US Fellowship (2019/072) for Women in STEMM (WISTEMM). The financial assistance from SERB in the form of research project (EEQ/2020/000565) and women excellence award (SB/WEA/09/2017) to Amritpal Kaur and UGC/BSR fellowship to Amarbir Kaur is also gratefully acknowledged.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

AUTHOR CONTRIBUTIONS

Amarbir Kaur: Data curation; Investigation; Writing-original draft. **Balwinder Singh:** Conceptualization; Formal analysis; Resources; Validation; Writing-review & editing. **Amritpal Kaur:** Conceptualization; Formal analysis; Funding acquisition; Investigation; Project administration; Resources. **Madhav Yadav:** Conceptualization; Formal analysis; Resources; Validation. **Narpinder Singh:** Formal analysis; Resources; Validation.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

ORCID

Balwinder Singh https://orcid.org/0000-0001-7114-6179
Amritpal Kaur https://orcid.org/0000-0003-2976-9940
Narpinder Singh https://orcid.org/0000-0002-9683-7846

REFERENCES

American Oil Chemists' Society. (1997). *Official methods and recommended practices of the AOCS* (7th ed.). AOCS Press.

American Oil Chemists' Society. (2017). *Official methods and recommended practices of the AOCS*. AOCS Press.

Aniołowska, M., & Kita, A. (2016). The effect of frying on glycidyl esters content in palm oil. *Food Chemistry*, *203*, 95–103. https://doi.org/10.1016/j.foodchem.2016.02.028

Choe, E., & Min, D. B. (2007). Chemistry of deep-fat frying oils. *Journal of Food Science*, *72*(5), R77–R86. https://doi.org/10.1111/j.1750-3841.2007.00352.x

Chotimarkorn, C., & Silalai, N. (2008). Addition of rice bran oil to soybean oil during frying increases the oxidative stability of the fried dough from rice flour during storage. *Food Research International*, *41*, 308–317. https://doi.org/10.1016/j.foodres.2007.12.007

Dana, D., & Saguy, I. S. (2006). Review: Mechanism of oil uptake during deep-fat frying and the surfactant effect-theory and myth. *Advances in Colloid and Interface Science*, *128–130*, 267–272. https://doi.org/10.1016/j.cis.2006.11.013

Debnath, S., Rastogi, N. K., Krishna, A. G., & Lokesh, B. R. (2012). Effect of frying cycles on physical, chemical and heat transfer quality of rice bran oil during deep-fat frying of poori: An Indian traditional fried food. *Food and Bioproducts Processing*, *90*(2), 249–256. https://doi.org/10.1016/j.fbp.2011.05.001

Dobarganes, C., & Márquez-Ruiz, G. (2015). Possible adverse effects of frying with vegetable oils. *British Journal of Nutrition*, *113*, S49–S57. https://doi.org/10.1017/S0007114514002347

Dung, C. H., Wu, S. C., & Yen, G. C. (2006). Genotoxicity and oxidative stress of the mutagenic compounds formed in fumes of heated soybean oil, sunflower oil and lard. *Toxicology in Vitro*, *20*(4), 439–447. https://doi.org/10.1016/j.tiv.2005.08.019

FAO/WHO. (2009, February 16–20). *Report of the 2first session of the Codex Alimentarius Committee on fats and oils*. WHO HQ.

Hashempour-Baltork, F., Torbati, M., Azadmard-Damirchi, S., & Savage, G. P. (2016). Vegetable oil blending: A review of physicochemical, nutritional and health effects. *Trends in Food Science & Technology*, *57*, 52–58. https://doi.org/10.1016/j.tifs.2016.09.007

Kaur, A., Singh, B., Kaur, A., & Singh, N. (2019). Chemical, thermal, rheological and FTIR studies of vegetable oils and their effect on eggless

muffin characteristics. *Journal of Food Processing and Preservation*, *43*(7), e13978. https://doi.org/10.1111/jfpp.13978

Kaur, A., Singh, B., Kaur, A., & Singh, N. (2020). Changes in chemical properties and oxidative stability of refined vegetable oils during short-term deep-frying cycles. *Journal of Food Processing and Preservation*, *44*(6), e14445. https://doi.org/10.1111/jfpp.14445

Kiralan, M., Ulas, M., Ozaydin, A., Ozdemir, N., Ozkan, G., Bayrak, A., & Ramadan, M. (2016). Changes in hexanal, thymoquinone and tocopherols levels in blends from sunflower and black cumin oils as affected by storage at room temperature. *Rivista Italiana Delle Sostanze Grasse*, *93*, 229–236.

Kiralan, M., Ulaş, M., Özaydin, A., Özdemır, N., Özkan, G., Bayrak, A., & Ramadan, M. F. (2017). Blends of cold pressed black cumin oil and sunflower oil with improved stability: A study based on changes in the levels of volatiles, tocopherols and thymoquinone during accelerated oxidation conditions. *Journal of Food Biochemistry*, *41*(1), e12272. https://doi.org/10.1111/jfbc.12272

Koohikamali, S., & Alam, M. S. (2019). Improvement in nutritional quality and thermal stability of palm olein blended with macadamia oil for deep-fat frying application. *Journal of Food Science and Technology*, *56*(11), 5063–5073. https://doi.org/10.1007/s13197-019-03979-0

Liu, Y., Li, J., Cheng, Y., & Liu, Y. (2019). Effect of frying oils' fatty acid profile on quality, free radical and volatiles over deep-frying process: A comparative study using chemometrics. *LWT-Food Science and Technology*, *101*, 331–341. https://doi.org/10.1016/j.lwt.2018.11.033

Liu, Y., Wang, Y., Cao, P., & Liu, Y. (2018). Combination of gas chromatography-mass spectrometry and electron spin resonance spectroscopy for analysis of oxidative stability in soybean oil during deep-frying process. *Food Analytical Methods*, *11*(5), 1485–1492. https://doi.org/10.1007/s12161-017-1132-7

Mohanty, B. P., Paria, P., Mahanty, A., Behera, B. K., Mathew, S., Sankar, T. V., & Sharma, A. P. (2012). Fatty acid profile of Indian shad Tenualosailisha oil and its dietary significance. *National Academy Science Letters*, *35*(4), 263–269. https://doi.org/10.1007/s40009-012-0042-x

Multari, S., Marsol-Vall, A., Heponiemi, P., Suomela, J. P., & Yang, B. (2019). Changes in the volatile profile, fatty acid composition and other markers of lipid oxidation of six different vegetable oils during short-term deep-frying. *Food Research International*, *122*, 318–329. https://doi.org/10.1016/j.foodres.2019.04.026

Nayak, P. K., Dash, U. M. A., Rayaguru, K., & Krishnan, K. R. (2016). Physio-chemical changes during repeated frying of cooked oil: A Review. *Journal of Food Biochemistry*, *40*(3), 371–390. https://doi.org/10.1111/jfbc.12215

Ng, C. Y., Leong, X. F., Masbah, N., Adam, S. K., Kamisah, Y., & Jaarin, K. (2014). Heated vegetable oils and cardiovascular disease risk factors. *Vascular Pharmacology*, *61*(1), 1–9. https://doi.org/10.1016/j.vph.2014.02.004

Pereira, E., Ferreira, M. C., Sampaio, K. A., Grimaldi, R., de Almeida Meirelles, A. J., & Maximo, G. J. (2019). Physical properties of Amazonian fats and oils and their blends. *Food Chemistry*, *278*, 208–215. https://doi.org/10.1016/j.foodchem.2018.11.016

Ramadan, M. F. (2013). Healthy blends of high linoleic sunflower oil with selected cold pressed oils: Functionality, stability and antioxidative characteristics. *Industrial Crops and Products*, *43*, 65–72. https://doi.org/10.1016/j.indcrop.2012.07.013

Ramadan, M. F., Amer, M. M. A., & Sulieman, A. E. R. M. (2006). Correlation between physicochemical analysis and radical-scavenging activity of vegetable oil blends as affected by frying of French fries. *European Journal of Lipid Science and Technology*, *108*(8), 670–678. https://doi.org/10.1002/ejlt.200600058

Saini, R. K., & Keum, Y. S. (2018). Omega-3 and omega-6 polyunsaturated fatty acids: Dietary sources, metabolism, and significance—A review. *Life Sciences*, *203*, 255–267. https://doi.org/10.1016/j.lfs.2018.04.049

Siddique, B. M., Muhamad, I. I., Ahmad, A., Ayob, A., Ibrahim, M. H., & Ak, M. O. (2015). Effect of frying on the rheological and chemical properties of palm oil and its blends. *Journal of Food Science and Technology*, *52*(3), 1444–1452. https://doi.org/10.1007/s13197-013-1124-6

Soleimanifar, M., Niazmand, R., & Jafari, S. M. (2019). Evaluation of oxidative stability, fatty acid profile, and antioxidant properties of black cumin seed oil and extract. *Journal of Food Measurement and Characterization*, *13*(1), 383–389. https://doi.org/10.1007/s11694-018-9953-7

Song, J., Kim, M. J., Kim, Y. J., & Lee, J. (2017). Monitoring changes in acid value, total polar material, and antioxidant capacity of oils used for frying chicken. *Food Chemistry*, *220*, 306–312. https://doi.org/10.1016/j.foodchem.2016.09.174

Soriguer, F., Rojo-Martínez, G., Dobarganes, M. C., García Almeida, J. M., Esteva, I., Beltrán, M., Ruiz De Adana, M. S., Tinahones, F., Gómez-Zumaquero, J. M., García-Fuentes, E., & González-Romero, S. (2003). Hypertension is related to the degradation of dietary frying oils. *The American Journal of Clinical Nutrition*, *78*(6), 1092–1097. https://doi.org/10.1093/ajcn/78.6.1092

Srivastava, S., Singh, M., George, J., Bhui, K., Saxena, A. M., & Shukla, Y. (2010). Genotoxic and carcinogenic risks associated with the dietary consumption of repeatedly heated coconut oil. *British Journal of Nutrition*, *104*(9), 1343–1352. https://doi.org/10.1017/S0007114510002229

Srivastava, Y., & Semwal, A. D. (2015). A study on monitoring of frying performance and oxidative stability of virgin coconut oil (VCO) during continuous/prolonged deep fat frying process using chemical and FTIR spectroscopy. *Journal of Food Science and Technology*, *52*(2), 984–991. https://doi.org/10.1007/s13197-013-1078-8

Suri, K., Singh, B., & Kaur, A. (2022). Impact of microwave roasting on physicochemical properties, maillard reaction products, antioxidant activity and oxidative stability of nigella seed (*Nigella sativa* L.) oil. *Food Chemistry*, *368*, 130777. https://doi.org/10.1016/j.foodchem.2021.130777

Suri, K., Singh, B., Kaur, A., Yadav, M. P., & Singh, N. (2019). Impact of infrared and dry air roasting on the oxidative stability, fatty acid composition, Maillard reaction products and other chemical properties of black cumin (*Nigella sativa* L.) seed oil. *Food Chemistry*, *295*, 537–547. https://doi.org/10.1016/j.foodchem.2019.05.140

Suri, K., Singh, B., Kaur, A., Yadav, M. P., & Singh, N. (2020). Influence of microwave roasting on chemical composition, oxidative stability and fatty acid composition of flaxseed (*Linum usitatissimum* L.) oil. *Food Chemistry*, *326*, 126974. https://doi.org/10.1016/j.foodchem.2020.126974

Talpur, M. Y., Kara, H., Sherazi, S., Ayyildiz, H. F., Topkafa, M., Arslan, F. N., Naz, S., & Durmaz, F. (2014). Application of multivariate chemometric techniques for simultaneous determination of five parameters of cottonseed oil by single bounce attenuated total reflectance Fourier transform infrared spectroscopy. *Talanta*, *129*, 473–480. https://doi.org/10.1016/j.talanta.2014.04.002

Tavakoli, H. R., Naderi, M., Jafari, S. M., & Naeli, M. H. (2019). Postmarketing surveillance of the oxidative stability for cooking oils, frying oils, and vanaspati supplied in the retail market. *Food Science & Nutrition*, *7*(4), 1455–1465. https://doi.org/10.1002/fsn3.982

Waghmare, A., Patil, S., LeBlanc, J. G., Sonawane, S., & Arya, S. S. (2018). Comparative assessment of algal oil with other vegetable oils for deep frying. *Algal Research*, *31*, 99–106. https://doi.org/10.1016/j.algal.2018.01.019

Zribi, A., Jabeur, H., Aladedunye, F., Rebai, A., Matthäus, B., & Bouaziz, M. (2014). Monitoring of quality and stability characteristics and fatty

acid compositions of refined olive and seed oils during repeated pan-and deep-frying using GC, FT-NIRS, and chemometrics. *Journal of Agricultural and Food Chemistry*, *62*(42), 10357–10367. https://doi.org/10.1021/jf503146f

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Kaur, A., Singh, B., Kaur, A., Yadav, M. P., & Singh, N. (2021). Impact of intermittent frying on chemical properties, fatty acid composition, and oxidative stability of 10 different vegetable oil blends. *Journal of Food Processing and Preservation*, 45, e16015. https://doi.org/10.1111/jfpp.16015