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ORIGINAL PAPER

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**María P. Jáuregui · Cecilia Riveros ·
Valeria Nepote · Nelson R. Grosso ·
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Abstract The purpose of this work was to evaluate the stability of fried-salted soybeans prepared in normal and high-oleic sunflower and normal peanut oils. Three products were obtained: fried-salted soybeans prepared in sunflower oil (FSS), in high-oleic sunflower oil (FSH) and in peanut oil (FSP). Products were stored for 112 days at 22 and 40 °C. Samples were removed from storage for chemical and sensory descriptive analyses. Fatty acid composition of raw soybeans changed after the frying process. Palmitic, linoleic, linolenic acids, iodine value and saturated/unsaturated ratio decreased while oleic acid and the oleic/linoleic ratio (O/L) increased after the frying process of soybeans. Soybeans fried in FSH had the highest O/L (2.42), followed by FSP (1.07), FSS (0.52), and finally by raw soybeans (0.37). Peroxide values higher than 10 mequiv O_2 kg^{-1} were reached after 23 days in FSS, 223 days in FSH, and 159 days in FSP at 22 °C. The shelf life was 10 (at 22 °C) and 7 (at 40 °C) times longer in FSH than in FSS. Soybeans fried in high-oleic sunflower and peanut oils had a higher stability than soybeans fried in sunflower oil, making them more resistant to lipid oxidation and the development of rancid flavors.

Keywords Soybeans · Frying · Fatty acid composition · Stability · Sensory analysis

M. P. Jáuregui · V. Nepote · M. F. Gayol (✉)
Instituto de Ciencia y Tecnología de los Alimentos, Facultad de Ciencias Exactas, Físicas y Naturales, IMBIV-CONICET, Universidad Nacional de Córdoba, Córdoba, Argentina
e-mail: fgayol@efn.uncor.edu

C. Riveros · N. R. Grosso
Quimica Biológica, Facultad de Ciencias Agropecuarias, IMBIV-CONICET, Universidad Nacional de Córdoba, CC 509, 5016 Córdoba, Argentina

Introduction

The soybean (*Glycine max.*) crop is an important source of food for man. Traditional soybean foods, including tofu, soy sauce, soybean paste and soybean sprouts are simple everyday food for Asians. In contrast, they are strange and sometimes hard to accept for Westerners [1].

Soybean is a legume with a high agricultural and economical value due to its unique chemical composition. Among cereal and other legume species, soybean seeds contain the highest amount of protein (35−45 %) and a relatively high content of oil (20−25 %). Raw soybean oil contains a wide range of unsaturated fatty acids and is rich in essential fatty acids. Soybean oil contains approximately 55 % linoleic and 25 % oleic acids [2, 3]. This fatty acid composition makes soybean products susceptible to lipid oxidation. Lipid oxidation occurs during storage of soybean products and contributes to the development of rancidity and undesirable flavors in foods where soybeans are an ingredient. The oxidation reactions lead indirectly to the formation of numerous aliphatic aldehydes, ketones, and alcohols. Simultaneously, oxidized and cardboard off-flavors increase in similar products such as fried-salted peanuts [4, 5].

Soybeans are an inexpensive and high quality protein source due to the presence of essential amino acids. Soybeans contain less sulfur amino acids (methionine and cystine) compared to meat or milk. This legume is an important protein source especially in places where milk or other animal products are not available [1].

Roasting and deep frying are common food preparation methods used to alter the flavor of foods. The roasting treatment should be uniform, in order to avoid raw and overcooked parts of food. The frying process; in contrast to other cooking processes; gives a uniform and fast product heating. Frying oil acts as a heat transfer medium and

contributes to the texture and flavor of fried food. Fried foods have a desirable flavor, color, and a crispy texture, which make deep-fat fried foods very popular with consumers. The high temperatures used (175–185 °C) "seal" the surface of the product, preventing a fast loss of steam, thus facilitating the cooking of the interior and allowing the product to remain more juicy. Foods fried at the optimum temperature and times have a golden brown color, are properly cooked and crispy, and have optimal oil absorption [6].

Soybeans have a high nutritional quality but they are not as extensively consumed as grains. The food industry uses soybeans mainly for oil extraction and proteins processing. However, to improve consumption of soybeans alternative products should be developed. The purpose of this work was to evaluate the oxidative stability of fried-salted soybeans prepared in different vegetable oils and stored at different temperatures.

Materials and Methods

Materials

Sound and mature soybean seeds (crop April 20, 2007, DM 3700 variety) were obtained from Intendente Alvear, La Pampa, Argentina. Soybean seeds were inspected and damaged and bruised seeds were removed manually.

The oils used to fry soybeans were normal and high-oleic sunflower oils and normal peanut oil.

Refined sunflower oil was obtained from "Molinos Cañuelas" (Cañuelas, Buenos Aires, Argentina). Refined high-oleic sunflower oil was obtained from "Granix" (Florida, Buenos Aires, Argentina). Peanut oil was obtained by cold pressing and filtering from blanched peanuts (*Arachis hypogaea* L.) type Runner provided by Lorenzati, Ruetsch y Cia. (Ticino, Córdoba, Argentina). The free fatty acid percentages (as oleic acid) were <0.1 % in refined sunflower oil and refined high-oleic sunflower oil, and 0.25 % in peanut oil.

Product Elaboration

Soybean seeds (7,500 g) were cooked in 50 L of water at 100 °C for 10 min. After that, the whole cooked soybean seeds (batches of 625 g) were drained and fried in the different vegetable oils (2.5 L) at 170 °C for 22 min in a fryer ("Moulinex" Principle, F30-A Series model, China). The frying oil was changed for a new one after every batch. Finally, the fried products were salted with 2 % sodium chloride [3]. Thus the following samples were obtained: fried-salted soybeans prepared in sunflower oil (FSS), in high-oleic sunflower oil (FSH), and in peanut oil (FSP).

Fatty Acid Composition of Frying Oils, Raw and Fried Soybean Products

Oil was obtained from the soybean products (raw soybeans and the different fried-salted products: FSS, FSH, FSP) by cold pressing using a 20 ton press (HE-DU, Hermes I. Dupraz SRL, Córdoba, Argentina).

Fatty acid methyl esters were obtained from the different oil samples (sunflower, high-oleic sunflower and peanut oils), raw soybean oil, and the oil extracted from the fried-salted soybeans (FSS, FSH and FSP) by *trans*-methylation with a solution of 3 % sulfuric acid in methanol, as previously described [7]. The fatty acid methyl esters were analyzed on a Perkin Elmer Clarus 500 gas–liquid chromatograph (Waltham, Massachusetts, USA) equipped with a flame ionization detector (FID). A Varian CP-Wax 52 CB capillary column (30 m × 0.25 mm; 0.25 μm i.d.) (Lake Forest, CA, USA) was used. The column temperature was programmed from 180 °C (held for 1 min) to 230 °C (20 °C min^{-1}). The separated fatty acid methyl esters were identified by comparing their retention times with those of authentic samples which were purchased from the Sigma Chemical Co. (St Louis, MO). Quantitative fatty acid analysis was performed using heptadecanoic acid methyl ester (Sigma Chemical Co.) as an internal standard. Iodine values (IV) were calculated from fatty acid composition using the following formula [8]: IV = (% C18:1 × 0.8999) + (% C18:2 × 1.814) + (% C18:3 × 2.737).

Storage Conditions and Sampling

After preparation, FSS, FSH and FSP samples were packaged in 27 × 28 cm plastic bags (Ziploc, Johnson & Son, Buenos Aires, Argentina) of high-density polyethylene with low oxygen barrier (1,500 cm^3 m^{-2} 24 h^{-1} bar^{-1}). The samples were stored at 22 °C (room temperature) and 40 °C (oven). Samples were removed from storage after 0, 28, 56, 91, and 112 days for chemical and descriptive analyses.

Chemical Analysis on Samples from Storage

The oil extracted by cold pressing from the different fried-salted samples was used for the following chemical analyses: peroxide, *p*-anisidine, conjugated dienes and trienes. The peroxide value (PV) was evaluated by the AOAC standard method [9] and expressed as milliequivalents active oxygen (mequiv O$_2$) kg^{-1} oil. Conjugated dienes (CD) and trienes (CT), and *p*-anisidine value (AV) were evaluated in an HP 8452A UV–visible diode array spectrophotometer (Hewlett Packard, Palo Alto, CA, USA) according to the COI [10] and IUPAC [11] standard methods, respectively.

Sensory Descriptive Analysis on Samples from Storage

Panel

A total of 12 trained panelists (9 female and 3 male) participated for descriptive analysis of fried soybean products in the storage study. All panelists were selected according to the following criteria: natural dentition, no food allergies, non-smokers, between the ages of 18–64, consume soybeans and/or soybean products at least once per month, available for the complete session, interest in participating, and able to verbally communicate regarding the product [12]. All panelists had to have a perfect score in a taste sensitivity test and the ability to identify five of seven commonly found food flavors before they qualified as panelists.

Training

All 12 panelists were trained and calibrated in four training sessions over 4 days. Each training session lasted 2 h for a total of 8 h. Descriptive analysis test procedures as described by Grosso and Resurreccion [12] and Gayol et al. [3] were used to train the panelists.

On the first day of training, panelists were given a review of concepts of sensory analysis. Then, they were asked to taste standard solutions of sucrose, sodium chloride, citric acid, and caffeine at varying concentrations and intensities that corresponded to points on a 150 mm unstructured line scale [12]. After that, all 12 panelists worked together to develop the language to describe perceivable product attributes. Fresh and rancid samples of fried-salted soybeans were presented to each panelist. A lexicon for peanut samples [13] was used to provide an initial list of attributes. Panelists described the following attributes in fried-salted soybeans: "brown color" and "gloss" for appearance, "roasted", "oxidized", "cardboard", and "raw/beany" for aromatics, "sweetness", "salty", "bitter" and "sour" basic tastes, "hardness" and "crunchiness" for texture, and "astringency" feeling factor. Panelists also identified references to be used to describe each attribute. Each panelist gave an intensity rating of each reference between 0 and 150 for each attribute.

On the second day of training, panelists reviewed descriptors, definitions, and reference standards to describe fried-salted soybean samples. Panelists tasted each reference and provided a rating. The panel was calibrated by obtaining an average panel rating with a standard deviation within 10 points. Panelists not rating within ±10 points of the mean rating were asked to re-evaluate the sample and adjust their rating until a consensus was reached. After that, medium fried-salted soybeans were presented as a "warm-up" sample to be used for each panelist as the initial sample during training and testing sessions [12].

On the third day of training, panelists finalized the definitions, descriptors, and reference standard intensities to describe the products. Then, the list of definitions and warm-up and reference intensity ratings were finalized. Definitions of attributes, standard references, and "warm-up" intensity ratings used in descriptive analysis of fried-salted soybeans are shown in Table 1. After that, panelists evaluated three samples with different degrees of oxidized flavors using paper ballots in order to calibrate themselves.

On the last day of training, panelists continued evaluating fried-salted soybean samples with different degrees of oxidized flavors to practice and to calibrate themselves within ±10 points of the mean ratings for each attribute of the samples.

Sample Evaluation

All samples were evaluated in partitioned booths under fluorescent light at room temperature. Five grams of product sample were placed into plastic cups with lids coded with 3 digit random numbers. Panelists evaluated nine samples per day plus a "warm-up" sample. The final lists of "warm-up" and reference intensity ratings and definitions were posted in the booths for all test sessions. Samples were tested using a complete randomized block design. The data were recorded on paper ballots.

Statistical Analysis

Analytical determinations were the average of triplicate measurements from three independent samples. The data were analyzed using the InfoStat software, version 2010.p (Facultad de Ciencias Agropecuarias, Universidad Nacional de Córdoba, Córdoba, Argentina). Statistical differences were estimated by ANOVA and considered significant at $p < 0.05$. Whenever ANOVA indicated a significant difference, a pair-wise comparison of means by least significant difference (LSD) was carried out. Correlation analyses were performed employing Pearson's coefficient. Regression equations were used to determine the effect of the independent variable (storage time) on chemical and sensory parameters. The regression analysis was performed adjusting a simple lineal model: $y = \beta_0 + \beta_1 x$, where 'y' was the dependent variable (chemical indicators and sensory attributes); β_0 was a constant that was equal the value of 'y' when the value of 'x' = 0; β_1 was the coefficient of 'x'; 'x' was the independent variable (time).

Table 1 Definitions of attributes, standard references, and warm-up intensity ratings used in descriptive analysis of fried-salted soybeans

Attribute[a]	Definition	Reference	Reference intensity[b]	Warm up intensity[b,c]
Appearance				
1. Brown color	The intensity or the strength of brown color from light to dark brown.	Color 4861[d]	65	70
2. Gloss	The amount of reflected light from product.	Chocolate peanuts[e]	58	80
Aromatics				
3. Roasted	The aromatic associated with medium roasted soybeans.	Dry roasted peanuts (JL SA, Ticino, Córdoba, Argentina)	76	55
4. Oxidized	The aromatic associated with rancid fats and oils.	Rancid Fried soybeans	76	5
5. Cardboard	The aromatic associated with wet cardboard.	Moist cardboard	41	5
6. Raw/beany	The aromatic associated with uncooked or raw soybeans.	Raw soybeans	80	5
Tastes				
7. Sweetness	Taste on the tongue associated with sucrose solutions.	2.0 % sucrose solution	20	12
		5.0 % sucrose solution	50	
		10 % sucrose solution	100	
		15 % sucrose solution	150	
8. Salty	Taste on the tongue associated with sodium chloride solutions.	0.2 % NaCl solution	25	100
		0.35 % NaCl solution	50	
		0.5 % NaCl solution	85	
9. Bitter	Taste on the tongue associated with bitter solutions such as caffeine.	0.05 % caffeine solution	20	5
		0.08 % caffeine solution	50	
		0.15 % caffeine solution	100	
10. Sour	Taste on the tongue associated with acid agents such as citric acid solutions.	0.05 % citric acid solution	20	2
		0.08 % citric acid solution	50	
		0.15 % citric acid solution	100	
Texture				
11. Hardness	Force needed to compress a food between molar teeth.	Almonds (Grandiet, Cordoba, Argentina)	74	60
12. Crunchiness	Force needed and amount of sound generated from chewing a sample with molar teeth.	Corn flakes (Granix, Buenos Aires, Argentina)	90	75
Feeling factor				
13. Astringency	The shrinking or puckering of the tongue surface caused by sub- stances such as tannins or alum.	Tea[f]	45	15
		Raw soybeans	40	

[a] Attributes listed in order as perceived by panelists

[b] Intensity ratings are based on 150-mm unstructured line scales

[c] Medium roasted soybeans

[d] Color number 4861, "Alba" color chart, Argentina

[e] Chocolate Peanut, "Arcor", Cordoba, Argentina

[f] Tea infusion "The Virginia", five bags in 1 L water at 90 °C for 2 h

Results and Discussion

Fatty Acid Composition of Frying Oils, Raw Soybeans and Fried-Salted Products

Fatty acid composition of the frying oils (sunflower, high-oleic sunflower, peanut), raw soybeans, and fried-salted soybeans (FSS, FSH, FSP) are presented in Table 2. The main fatty acids found in all samples were oleic acid (18:1n-9), linoleic acid (18:2n-6) and palmitic acid (16:0). Palmitic (16:0) and stearic (18:0) were the most abundant saturated fatty acids (SFA). Oleic (18:1) and linoleic (18:2) were the most important of the unsaturated fatty acids in all samples. Significant differences ($p < 0.05$) were found between samples in most of the fatty acids percentages. High-oleic sunflower oil had the highest amount of oleic

Table 2 Fatty acid composition ($n = 3$) of the frying oils (sunflower, high-oleic sunflower, peanut), raw soybeans, and fried-salted soybeans prepared in sunflower oil (FSS), in high-oleic sunflower oil (FSH) and in peanut oil (FSP)

Fatty acids		Composition (g × 100 g^{-1} fatty acids)														
		Frying oils						Raw soybean		Fried-salted soybeans						
		Sunflower		High-oleic sunflower		Peanut				FSS		FSH		FSP		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Saturated															
Palmitic acid	C16:0	5.9	0.2b	3.8	0.1a	8.1	0.2d	9.6	0.2f	6.9	0.2c	5.7	0.1b	8.6	0.2e
Stearic acid	C18:0	2.9	0.1b	3.0	0.1b	1.7	0.1a	3.3	0.5bc	3.3	0.1bc	3.7	0.2c	2.9	0.2b
Arachidic acid	C20:0	0.2	0.0a	0.3	0.0a	1.1	0.3b	0.3	0.1a	0.4	0.1a	0.3	0.1a	0.9	0.3b
Behenic acid	C22:0	0.7	0.0a	1.0	0.0a	3.3	0.8c	0.3	0.1a	0.5	0.1a	0.7	0.2a	2.5	0.6b
Lignoceric acid	C24:0	0.3	0.0a	0.4	0.0a	1.7	0.4b	tr**	a	0.2	0.0a	0.2	0.1a	1.6	0.4b
Total		9.9	0.1ab	8.5	0.2a	15.9	1.8c	26.3	0.7e	11.3	0.6b	10.7	0.7b	16.6	1.3c
Monounsaturated															
Palmitoleic acid	C16:1	0.6	0.0c	tr**	a	tr**	a	tr**	a	0.2	0.0b	0.2	0.1b	tr**	a
Oleic acid	C18:1	38.3	0.5c	84.2	1.1g	52.8	0.8e	21.1	0.2a	28.8	0.4b	61.1	1.0f	40.7	0.6d
Eicosenoic acid	C20:1	0.3	0.1bc	0.3	0.1c	2.2	0.0e	0.1	0.0a	0.3	0.0c	0.2	0.0b	1.4	0.0d
Total		38.9	0.0d	84.5	1.2h	55.0	0.8f	21.2	0.2a	29.1	0.5c	61.4	1.1g	42.0	0.6e
Polyunsaturated															
Linoleic acid	C18:2	51.1	0.2e	6.9	0.0a	29.1	0.2c	57.2	0.6g	55.4	0.3f	25.2	0.2b	38.2	0.3d
Linolenic acid	C18:3	nd**	a	nd**	a	nd**	a	8.9	0.2d	2.5	0.0b	2.7	0.0bc	2.7	0.0c
Total		51.1	0.2e	6.9	0.0a	29.1	0.2c	66.0	0.8i	58.0	0.3g	27.9	0.2b	40.9	0.3d
Oleic/linoleic ratio	O/L	0.75	0.01c	12.22	0.12g	1.81	0.01e	0.37	0.04a	0.52	0.01b	2.42	0.02f	1.07	0.01d
Iodine value	IV	123	0e	88	1a	98	1b	142	0g	129	1f	106	1c	110	1d
Saturated/unsaturated ratio	S/U	0.11	0.00ab	0.09	0.00a	0.19	0.02c	0.30	0.02d	0.13	0.01b	0.12	0.01b	0.2	0.01c

Different letters in each row indicate significant differences between samples ($\alpha = 0.05$)

** *tr* trace value (<0.03 g × 100 g^{-1}), *nd* not detected

acid (84.2 %), followed by the product FSH (61.1 %), while raw soybeans had the lowest content (21.1 %). Raw soybeans had the highest content of linoleic and linolenic acids (57.2 and 8.9 %, respectively) followed by FSS (55.4 and 2.5 %, respectively). FSH showed the lowest linoleic content (25.2 %) in comparison with the other samples.

High-oleic sunflower oil and FSH had the highest O/L (oleic/linoleic) ratios (12.22 and 2.42, respectively), followed by peanut oil and FSP (1.81 and 1.07, respectively), then sunflower oil and FSS (0.75 and 0.52, respectively), and finally by raw soybeans (0.37).

The raw soybeans had a higher S/U (saturated/unsaturated) ratio (0.30) than the other samples. This was mainly due to the higher content of palmitic acid and the lower content of oleic acid in raw soybeans.

The iodine value is a measure of the unsaturation degree and instability of lipids. The Argentine Food Code [16] indicates that soybean, sunflower and peanut oils should have an IV between 125–137, 119–138 and 92–106, respectively. High-oleic sunflower oil had the lowest IV in comparison with the other oils and soybean products. Fried-salted soybeans prepared in this oil (FSH) had a lower IV value than the other products, followed by FSP and FSS.

The fatty acid pattern of a vegetable oil is one of the most important factors influencing lipid oxidation. It is not recommended that frying fats have a high polyunsaturated fatty acid (PUFA) content, especially long-chain PUFA since their speed of oxidation is much higher compared to monounsaturated fatty acids (MUFA) and SFA. Different speeds of lipid oxidation among the fatty acids can be explained by various energies required for the abstraction of one H atom from a fatty acid molecule as the initial step in lipid oxidation. Dissociation energies of stearic, oleic, linoleic and linolenic acids are 410, 322, 272, and 167 kJ mol^{-1}, respectively [17]. These results indicate that the fatty acid composition of raw soybeans changed after the frying process in the different vegetable oils. That could be due to the partial absorption of the frying oils in the soybean product [4, 14]. In general, palmitic, linoleic and linolenic acids decreased while oleic acid increased after the frying of the soybean seeds. In addition, the IV and S/U decreased, and O/L increased in the fried products. These fatty acid changes could have a positive effect on increasing the shelf life of the fried-salted soybeans. Previous works on fried peanuts reported changes in the chemical and fatty acid compositions due to the frying process in sunflower oil [4, 14]. Thus, our results reaffirm the fatty acid changes in fried products.

Chemical Analysis

The changes in peroxide, *p*-anisidine values, conjugated dienes and trienes of the samples FSS, FSH and FSP during storage at 22 and 40 °C are shown in Fig. 1. In general, these variables increased during storage time. The increase was more notable at 40 °C than at 22 °C, mainly in PV and CD indicators.

FSS had a significantly ($p < 0.05$) higher PV with respect to the other samples after day 0 at both temperatures (22 and 40 °C). The PV of FSP and FSH stored at 22 °C increased minimally during the storage. These samples had PV lower than 10 mequiv O_2 kg^{-1} fat (maximum PV allowed in food for consumption, according to Food Code from Argentina) [16]. FSP and FSH exceeded PV 10 mequiv O_2 kg^{-1} after 91 days of storage at 40 °C. FSS exceeded the value allowed by the CAA after 28 days, having PV of 50 and 110 mequiv O_2 kg^{-1} after 112 days of storage at 22 and 40 °C, respectively.

Significant differences ($p < 0.05$) in the AV were found between the products stored at both temperatures. In general, FSS had a higher and FSH had a lower AV during storage. FSP showed intermediate *p*-anisidine values. The AV was less affected by storage temperature than PV. FSP and FSH had similar AV when stored at 22 and 40 °C. *p*-anisidine is a method used to detect secondary products of oxidation. The autoxidation reactions in foods lead to overall oxidative breakdown of poly and MUFA. The speed of the oxidation is mainly dependent of the fatty acid, where higher unsaturated fatty acids present in the composition of the oil leads to increased oxidation. In particular, during the frying process, the oil and food are continuously and repeatedly exposed to elevated temperatures in air and moisture. A number of chemical reactions occur during this time, including oxidation and hydrolysis, as well as changes due to thermal decomposition. These decomposition products formed during frying are mainly volatile compounds such as aldehydes, ketones, or alcohols and nonvolatiles due to chemical changes (breakdown of fatty acids), followed by an increase in the p-anisidine value and free fatty acids [18]. The production of polar compounds is higher in high linoleic sunflower oil, followed by high oleic sunflower oil when thermoxidation process occurs during the frying [17, 19]. In this study, high linoleic sunflower oil was used during the frying process. This oil is much more polyunsaturated than peanut and high oleic sunflower oils. This effect could explain the higher *p*-anisidine value at time "0" FSS at 23 and 40 °C with respect to the other samples.

Conjugated dienes and conjugated trienes contents showed similar behavior to PV and AV. In general, FSS had higher CD and CT contents than the other samples during storage at both temperatures. FSP and FSH had an insignificant CD increase during the 112 days of storage at 22 °C. Conjugated dienes was more affected by the storage temperature than trienes. All samples had higher CD when they were stored at 40 °C than at 22 °C.
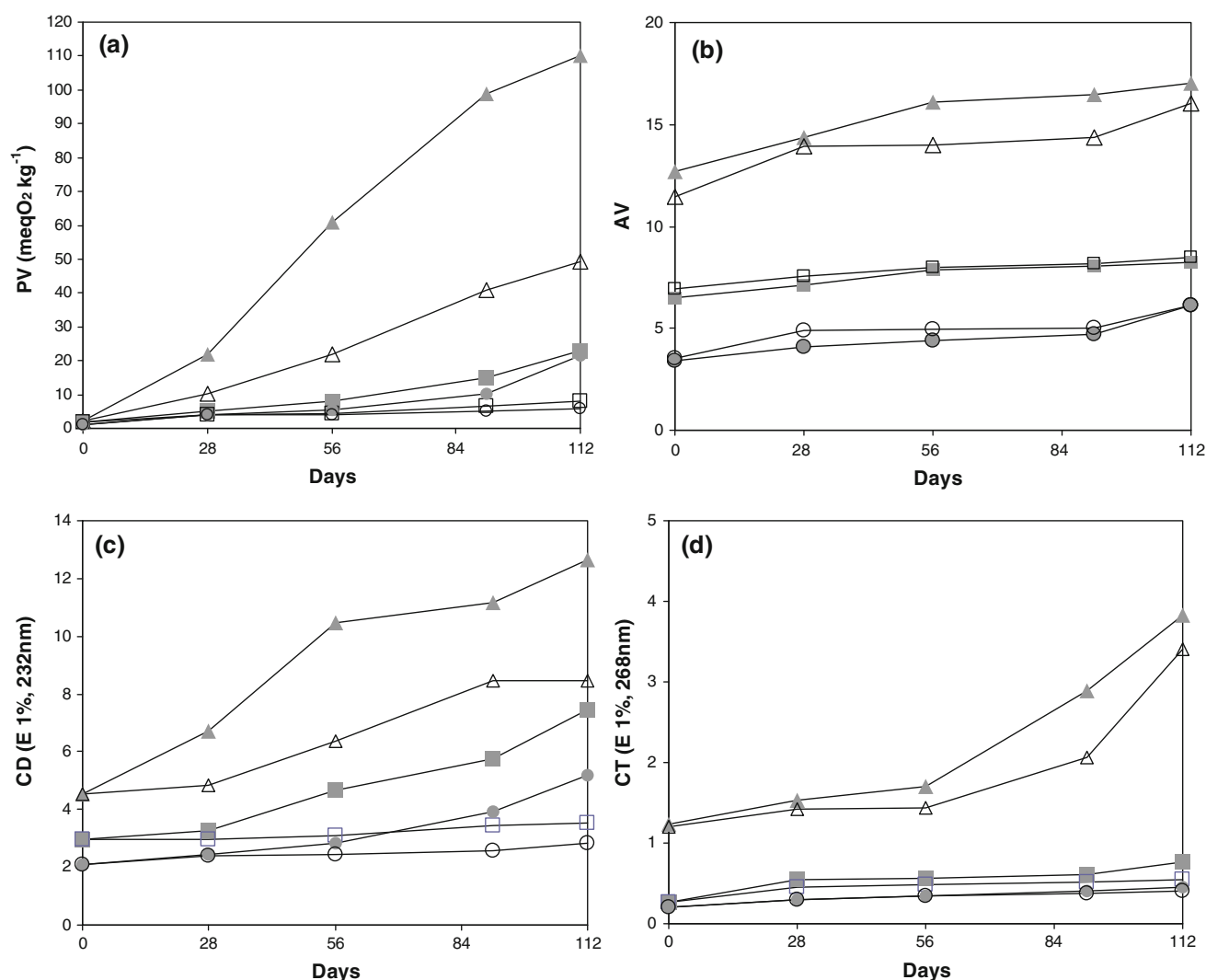
Fig. 1 **a** Peroxide value (PV), **b** *p*-anisidine value (AV), **c** conjugated dienes (CD), **d** conjugated trienes (CT) in fried-salted soybeans prepared in sunflower oil (FSS), in high-oleic sunflower oil (FSH), and in peanut oil (FSP) during storage time at 22 and 40 °C. Symbols indicate: —△— FSS-22 °C, —▲— FSS-40 °C, —⊖— FSH-22 °C, —⊙— FSH-40 °C, —⊡— FSP-22 °C, —▣— FSP-40 °C

Linoleic and linolenic fatty acids are susceptible to oxidation [3, 4]. A higher O/L ratio is associated with greater lipid stability [4, 14, 15]. Previous works on fried-salted peanuts [4, 5] reported that PV, CD and AV increased during the storage time. Fried-salted peanuts prepared with kernels of high-oleic peanuts had better oxidative stability than those prepared with normal peanuts [4].

Vegetable oils present natural antioxidants that may contribute to their oxidative stability. Tocochromanols represent a family of natural, structurally related compounds known as tocopherols and tocotrienols. For all homologues, the basic structural unit is the chromanol ring system (2-methyl-6-hydroxy-chroman) which is responsible for the antioxidant activity acting as a chain-breaking antioxidant [20]. Tocopherols are antioxidants possessing a

"carry-through" property, which is defined as the ability of an antioxidant to survive the technological process, such as heat treatment or refined process, and transfer the stabilizing activity to the final product [21]. There are four tocopherols (α, β, γ and δ-tocopherols). δ-tocopherol was shown to be much more efficient at protecting frying fat at 160 °C than α-tocopherol [22]. α-Tocopherol is oxidized more quickly in oils used for deep-fat frying potatoes than the other tocopherols [17]. In a more recent study about the stability of tocochromanols at frying conditions, the most stable was α-tocopherol; the least stable γ-tocopherol [23]. Similar finding were made by Aladedunye and Przybylski [24], who also found γ-tocopherol was less stable at 185 °C. Total tocopherols of 1,293 ppm in soybean oil, 738 ppm in sunflower oil, 265 ppm in high oleic sunflower oil and 482 ppm in Peanut oil have been reported [25]. The

tocopherol amount in soybean oil should help the fried soybean product retain stability. In addition, the different vegetables oils (sunflower, high oleic sunflower and peanut oils) used for frying the soybeans have different amounts of tocopherols being higher in sunflower oil and lower in high oleic sunflower oil according to O'Brien [25]. However, this higher amount of natural antioxidants (tocopherols) present in sunflower oil did not increase the stability of the product in comparison with the other frying oils (peanut and high oleic sunflower oils).

Descriptive Analysis

The products did not significant differed in brown color, brightness, oxidized, sweet, salty, and hardness (Table 3). FSH had a higher roasted flavor and crunchiness, and a lower raw/beany flavor, astringency, and sour and bitter tastes than the other products.

All descriptive attributes (roasted, oxidized, cardboard, and raw/beany flavors, sweetness, salty, bitter, sour, brown color, gloss, hardness, crunchiness, and astringency) were evaluated in fried-salted soybeans during storage at different temperatures; however not all sensory characteristics changed significantly over storage times. The intensity ratings of the attributes that did not significantly change during storage were: raw/beany flavor (7.93–9.67), sweetness (10.93–11.40), salty (83.73–86.87), bitter (10.00–11.60), brown color (68.47–69.53), hardness (62.80–63.53), and astringency (15.07–16.67). The attributes that changed during storage of the samples are presented in Figs. 2 and 3. Figure 2 shows the changes in roasted, oxidized and cardboard flavor intensities. Figure 3 shows the changes in gloss, sour and crunchiness intensity ratings of fried-salted soybeans during storage at 22 and 40 °C.

Oxidized, cardboard and sour attributes increased with storage while gloss, roasted, and crunchiness attributes decreased during the storage at both temperatures. Significant differences ($p < 0.05$) in these attributes between the samples were detected at 40 °C. FSS had higher oxidized, cardboard and sour sensory scores than the other products. In addition, this product had greater roasted and crunchiness reductions in comparison with FSP and FSH. FSP and FSH had similar sensory changes during storage at both temperatures, without significant differences.

Previous works on fried-salted peanuts reported intensity ratings of sensory attributes from descriptive analysis [4, 5]. Fried-salted soybean showed lower intensity ratings of roasted, oxidized, cardboard, sweet and bitter, and higher intensity ratings of brown color, gloss, salty, sour, crunchiness and hardness than fried-salted peanut. Other results from sensory descriptive analysis on peanut products from Argentina were presented by Riveros et al. [15] and Nepote et al. [26]. Those authors found intensity ratings of roasted

Table 3 Means and standard deviations ($n = 3$) of sensory attribute intensities from descriptive analysis of fresh products (storage time = 0 days): fried-salted soybeans prepared in sunflower oil (FSS), in high-oleic sunflower oil (FSH) and in peanut oil (FSP)

| Sensory attributes	Fried-salted soybeans		
	FSH[*]	FSS[*]	FSP[*]
Appearance			
1. Brown color	68.53 ± 3.13a	68.47 ± 2.26a	69.53 ± 2.37a
2. Brightness	80.33 ± 1.27a	79.47 ± 1.85a	80.73 ± 2.72a
Aromatic			
3. Roasted soybeans	51.67 ± 3.91b	49.53 ± 4.47ab	48.33 ± 4.42a
4. Oxidized	4.40 ± 2.37a	4.73 ± 2.74a	5.33 ± 3.10a
5. Cardboard	5.60 ± 1.04a	6.13 ± 1.61ab	6.73 ± 1.84 b
6. Raw/beany	7.93 ± 4.19a	9.00 ± 4.00ab	9.67 ± 4.28b
Feeling factor			
7. Astringency	15.07 ± 0.45a	16.67 ± 3.56b	16.13 ± 2.43ab
Taste			
8. Sweet	11.40 ± 1.96a	10.93 ± 0.94a	10.93 ± 1.01a
9. Salty	86.87 ± 5.76a	84.47 ± 9.1a	83.73 ± 9.38a
10. Sour	5.33 ± 0.71a	6.27 ± 1.31b	6.40 ± 1.28b
11. Bitter	10.00 ± 0.00a	11.40 ± 2.9b	11.60 ± 3.19b
Texture			
12. Crunchiness	77.00 ± 3.02b	74.40 ± 3.6a	74.80 ± 3.79a
13. Hardness	62.80 ± 5.16a	63.53 ± 6.1a	63.40 ± 5.56a

* Means followed by different letters in each row indicate significant differences between samples ($\alpha = 0.05$)

of 55–57 and 50–56 in peanut paste and roasted peanuts, respectively. Grosso and Resurreccion [12] found intensity ratings of roasted peanutty flavor of 67 and 63 in roasted peanuts and cracker coated peanuts from USA, respectively. Previous works on peanut products reported the cardboard and oxidized attributes increased and roasted peanutty flavor decreased during storage [4, 5, 15].

Correlation and Regression Analysis

The variables of interest in this study were PV, AV, CD, CT, oxidized, cardboard, roasted flavors, sour, gloss and crunchiness because they changed during storage. Correlation coefficients between these variables and with oleic/linoleic ratio (O/L) and iodine value (IV) in fried-salted soybeans are presented in Table 4.

The chemical variables PV and CD showed significant and positive correlation (coefficients higher than 0.60) with the sensory attributes oxidized, cardboard and sour, and with the IV of the soybean products. All chemical indicators (PV, AV, CD, and CT) were negatively correlated with the O/L ratio of samples. The correlation analysis indicated that fatty acid composition (O/L and IV) had an effect on the chemical stability of the soybean products. The roasted
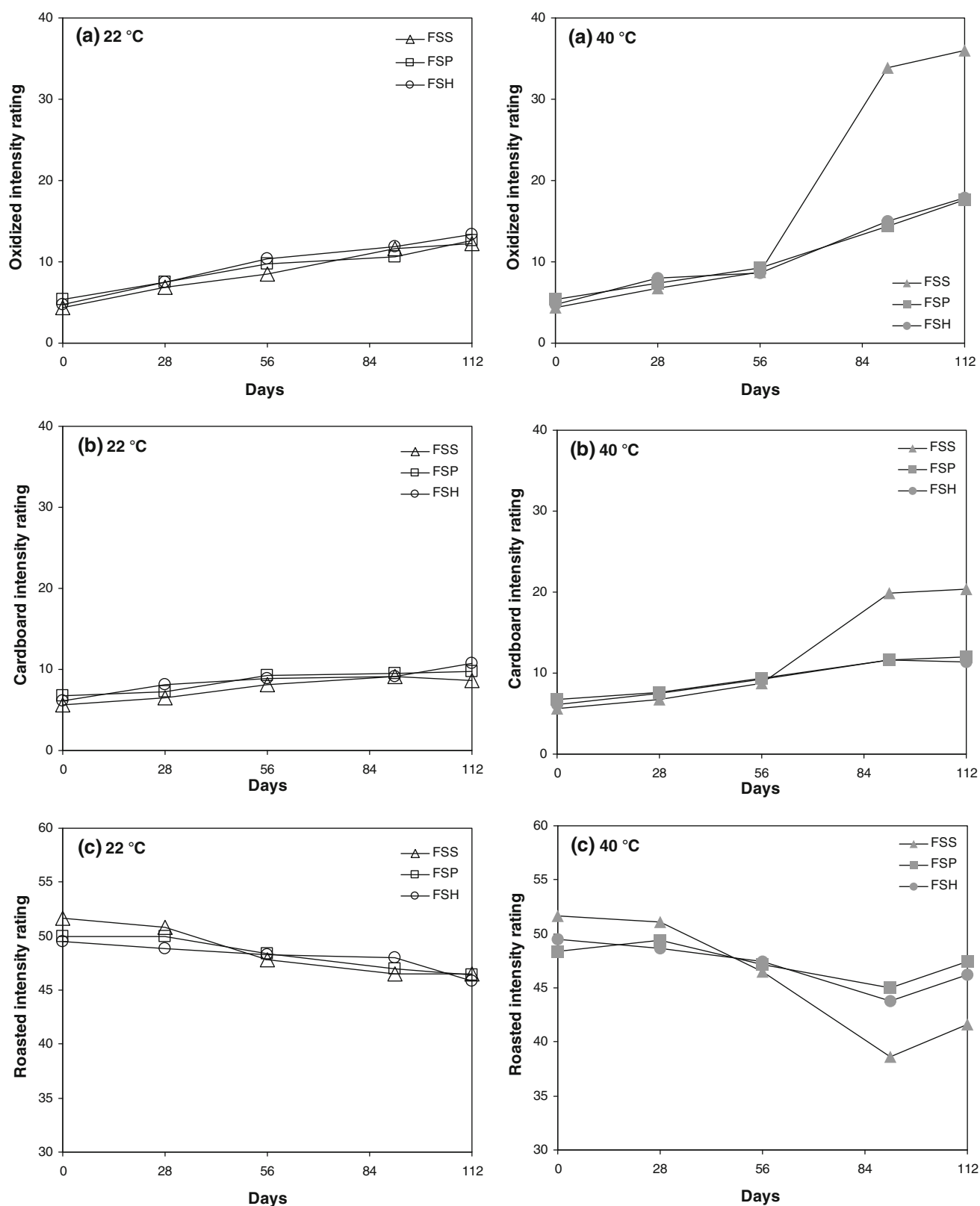
Fig. 2 Intensity rating of **a** oxidized, **b** cardboard, and **c** roasted in fried-salted soybeans prepared in sunflower oil (FSS), in high-oleic sunflower oil (FSH), and in peanut oil (FSP) during storage time at 22 and 40 °C. Symbols indicate: FSS-22 °C, FSS-40 °C, FSH-22 °C, FSH-40 °C, FSP-22 °C, FSP-40 °C
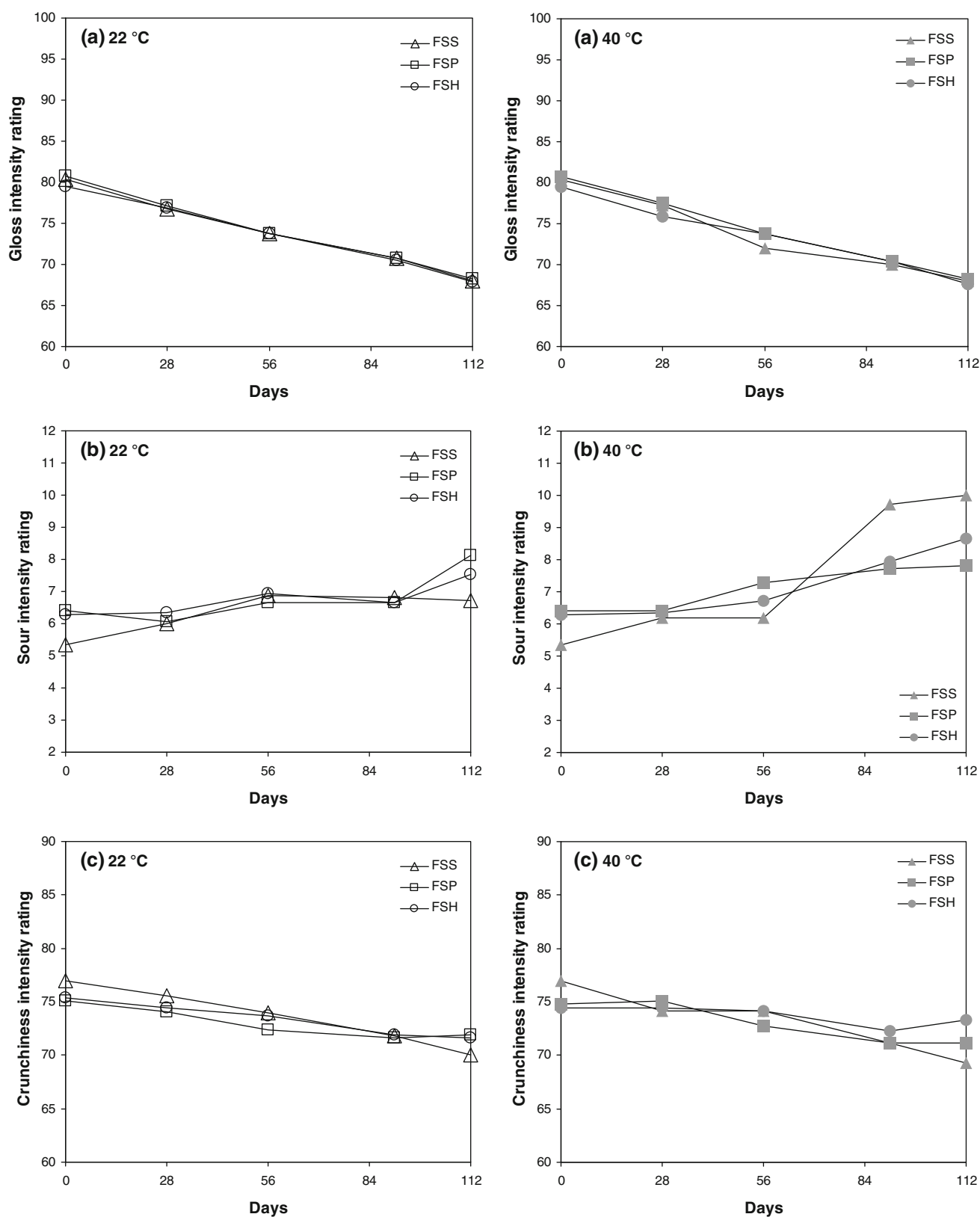
Fig. 3 Intensity rating of **a** gloss, **b** sour, and **c** crunchiness in fried-salted soybeans prepared in sunflower oil (FSS), in high-oleic sunflower oil (FSH), and in peanut oil (FSP) during storage time at 22 and 40 °C. Symbols indicate: ─△─ FSS-22 °C, ─▲─ FSS-40 °C, ─○─ FSH-22 °C, ─●─ FSH-40 °C, ─□─ FSP-22 °C, ─■─ FSP-40 °C

Table 4 Correlation coefficients between chemical parameters and sensory attributes in fried-salted soybeans during storage

Variables	PV	AV	CD	CT	Gloss	Roasted	Oxidized	Cardboard	Sour	Crunchiness	O/L
AV	**0.74****										
CD	**0.92****	**0.78****									
CT	**0.90****	**0.88****	**0.81****								
Gloss	**−0.49****	−0.22	**−0.43***	**−0.37***							
Roasted	**−0.74****	−0.26	**−0.62****	**−0.50****	**0.74****						
Oxidized	**0.83****	**0.39***	**0.75****	**0.64****	**−0.69****	**−0.89****					
Cardboard	**0.80****	0.33	**0.73****	**0.58****	**−0.68****	**−0.92****	**0.99****				
Sour	**0.67****	0.18	**0.60****	**0.43***	**−0.73****	**−0.90****	**0.93****	**0.94****			
Crunchiness	**−0.54****	−0.15	**−0.42***	**−0.37***	**0.80****	**0.80****	**−0.73****	**−0.75****	**−0.75****		
O/L	**−0.99****	**−0.95****	**−0.97****	**−0.76***	**−0.67***	−0.57	0.09	0.19	0.59	−0.55	
IV	**0.87****	**0.96****	**0.94****	**0.99****	0.64	0.66	−0.55	−0.61	−0.51	0.62	**0.60****

Bold values indicate significant correlation coefficients

* Significant at $p \leq 0.05$

** Significant at $p \leq 0.01$

PV peroxide value, *AV* p-anisidine value, *CD* conjugated dienes, *CT* conjugated trienes, *O/L* oleic/linoleic ratio, *IV* iodine value

Table 5 Regression coefficients and R^2 from prediction equations of peroxide value (PV), p-ansidine value (AV), and conjugated dienes and trienes (CD and CT) in fried-salted soybeans prepared in sunflower oil (FSS), in high-oleic sunflower oil (FSH), and in peanut oil (FSP) during storage time at 22 and 40 °C

Dependent variable	Fried-salted soybean	Linear regression coefficients*							
		22 °C				40 °C			
		β_o	β_1	**	R^2	β_o	β_1	**	R^2
PV	FSS	−0.15059	0.43691	b	0.98954	−0.03597	1.02502	b	0.98642
	FSH	1.99931	0.03590	a	0.86159	−0.68301	0.16047	a	0.82367
	FSP	2.07404	0.04996	a	0.96582	0.19137	0.18106	a	0.93970
AV	FSS	12.07885	0.03295	b	0.82844	13.19517	0.03712	b	0.91653
	FSH	3.87467	0.01790	a	0.7882	3.37041	0.02031	a	0.86596
	FSP	7.08468	0.01285	a	0.95219	6.70357	0.01492	a	0.9192
CD	FSS	4.21359	0.04053	b	0.94740	4.99786	0.07164	b	0.94056
	FSH	2.14192	0.00579	a	0.93870	1.78357	0.02635	a	0.91316
	FSP	2.87731	0.00548	a	0.88699	2.54769	0.03952	a	0.94550
CT	FSS	0.6974	0.0176	a	0.8011	0.92954	0.02276	b	0.89899
	FSH	0.22251	0.00173	a	0.9455	0.21257	0.00219	a	0.98540
	FSP	0.32418	0.00219	a	0.7948	0.34111	0.00364	a	0.82858

* Linear regression coefficients for the general regression equation: $Y = \beta_o + \beta_1 X$, where Y = dependent variable (AV, PV, CD, CT) and X = independent variable (days of storage)

** Different letters indicate significant differences in regression slopes between samples ($\alpha = 0.05$)

flavor also showed negative and significant correlation coefficients with PV and CD, oxidized, cardboard and sour. These negative correlations indicated that roasted flavor decreased when PV, CD, oxidized and cardboard flavors increased during storage time. The roasted flavor could be considered a positive attribute, while oxidized and cardboard flavors are negative attributes related to lipid deterioration in soybean and similar products [4, 5].

The variables that are related to lipid oxidation (PV, AV, CD, CT, oxidized, cardboard and sour flavors) had

positive slopes, indicating a linear increase with storage time (Table 5). The sensory attributes roasted flavor, gloss, and crunchness had negative slopes. The dependent variables PV, AV, CD, CT values, and oxidized, cardboard, roasted flavors, gloss, and crunchness showed $R^2 > 0.70$ in all products and temperatures (22 and 40 °C), indicating that these variables are good predictors of quality changes. Therefore, these regression equations could be used to predict the effect of storage time at 22 and 40 °C on these soybean products. The variables that showed significant

differences in regression slopes between samples at both storage temperatures (22 and 40 °C) were PV, AV and CD values. CT showed significant differences in regression slopes between samples at 40 °C. FSS had higher PV, AV and CD regression slopes at both temperatures than the other samples (FSH and FSP). Samples did not differed significantly in the regression slopes of the sensory variables.

In other works [4, 5, 12, 15], an increase in the intensity ratings of cardboard and oxidized and a decrease in roasted peanutty flavor in peanut products during the storage time was observed. Roasted peanutty flavor can be attributed to the presence of pyrazines. Crippen et al. [27] and Warner et al. [28] found that the roasted peanutty flavor intensity and alkylpyrazines decreased in stored roasted peanuts.

In the Food Code from Argentina, 10 mequiv O_2 kg^{-1} is the maximum level of the peroxide value allowed for edible oils [16]. Peroxide values of 10 mequiv O_2 kg^{-1} may be useful as an endpoint of quality for fried-salted soybeans in the different oils. Therefore, shelf life was estimated as the time to reach this peroxide value of 10 mequiv O_2 kg^{-1} from the linear regression of the PV-time curves [29]. Using the prediction equations, peroxide values higher than 10 mequiv O_2 kg^{-1} were reached after 23 days in FSS at 22 °C, 223 days in FSH at 22 °C, 159 days in FSP at 22 °C, 10 days in FSS at 40 °C, 67 days in FSH at 40 °C, and 54 days in FSP at 40 °C. Thus, the self life was of 10 (at 22 °C) and 7 (at 40 °C) times longer in FSH than FSS.

Conclusions

The results of this work indicate that the soybean products fried in high-oleic sunflower oil and peanut oil showed higher stability than the soybeans fried in sunflower oil, making them more resistant to lipid oxidation and the development of rancid flavors. High-oleic sunflower and peanut oils could be used to fry other products to increase shelf-life and improve the stability of foods containing a high lipid content.

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