Multivariate Sensory Characteristics of Low and Ultra-Low Linolenic Soybean Oils Displayed as Faces

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ABSTRACT: The effects of linolenic acid (18:3) concentration, combined with TBHQ addition, temperature, and storage time, on the flavor stability of soybean oils (SBO) were evaluated. A descriptive panel was trained to evaluate the overall oil quality and the intensity of individual flavors of SBO during 12 mon of storage under fluorescent light at both 21 and 32°C. Chernoff faces were used to achieve a simplified and integrated interpretation of the multivariate sensory data and to facilitate the interpretation of the vast amount of the data. In early storage, SBO with low 18:3 (2.2% 18:3, LLSBO) showed better flavor stability than did SBO with ultra-low 18:3 (1.0% 18:3, ULSBO). This trend disappeared during storage. During 10- to 12-mon storage, a painty flavor became predominant in all oils, which may have made it difficult for panelists to detect differences in treatment effect on flavor characteristics of SBO. During early storage, oils with TBHQ addition had poorer overall oil quality and stronger beany, painty, and fishy flavors than did oils without TBHQ addition. This trend disappeared as storage time progressed to 10 mon. Oils stored at 32°C had poorer overall oil quality and stronger painty, fishy, and beany flavors than did oils stored at 21°C starting from 2-mon storage.

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Soybean oil (SBO) is very prone to flavor deterioration, and sensory evaluation provides the ultimate judgment of its flavor stability. The recommended practice of the AOCS is to evaluate overall oil quality and the intensity of individual flavors. The number of flavors that can be present in SBO can be as many as 15 or more (1). Therefore, the resulting data are multivariate, because they are made up of complex interrelated elements. The standard display of data, such as numbers, may obscure the recognition of relationships among elements. To make overall perception and interrelationships immediately apparent, and to provide a more accurate judgment as a well-integrated pictorial display, one may use multivariate data analysis methods. There are reports of the use of multivariate data analysis methods, such as principal component analysis, factor analysis, and generalized procrustes analysis in the sensory evaluation of different food products (2–4); however, the use of Chernoff faces to characterize sensory evaluation of food products or SBO was not found in the literature.

This paper focuses on the descriptive sensory analysis of SBO flavor stability and the use of Chernoff faces (5) to simplify the interpretation and graphically display an abundant amount of sensory data. This method involves letting the size, shape, or orientation of each feature of a cartoon face represent a particular variable (overall flavor quality or the individual flavor descriptor in the current work) (6). Thus, one might let the area of the face represent overall flavor quality of the oil, the shape of the face a fishy flavor, the length of the nose a third characteristic, and so on. Programs have been developed that allow the representation of up to 15 (7) or 20 variables (8). These characteristics inspired the authors to explore the use of Chernoff faces.

The specific objectives of the current work were to report the sensory evaluation, by using Chernoff faces, of SBO with low-linolenic acid (18:3; ~2.2%) and ultra-low-18:3 concentrations (~1.0%), with and without the addition of TBHQ, and at two storage temperatures (21 and 32°C) during storage for 12 mon. A related paper (9) gave complete information on the physical, chemical, and general sensory tests used to assess these oil treatments.

MATERIALS AND METHODS

SBO and design. Soybeans (*Glycine max*) with low-18:3 (LL, 2.2%) and ultra-low-18:3 (UL, 1.0%) concentrations, grown in summer 2000 in Iowa (weather zone 4), were obtained from Protein Technologies, Inc. (St. Louis, MO). The LL soybeans were crushed by the Montana Power Group (Culverston, MT), and the UL soybeans were crushed at the POS Pilot Plant Corporation (Saskatoon, Saskatchewan, Canada). Both oils were hexane-extracted, and refined, bleached, deodorized, and bottled at the POS Plant. Citric acid (50 ppm) was added to the oils during the cool-down stage of deodorization. The antioxidant TBHQ (100 ppm) was added to half of each oil type at the deodorization step before bottling in co-extruded polyethylene terephthalate (PET) plastic bottles. The bottles were sparged with nitrogen until they contained less than 2% oxygen in the headspace, then sealed. Bottled oils were sent to Iowa State University (ISU; Ames, IA) for evaluation. Thus, four SBO treatments were tested, including low-18:3 SBO (LLSBO), LLSBO with the addition of 100 ppm TBHQ (LLSBOW),

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ultra-low-18:3 SBO (ULSBO), and ULSBO with the addition of 100 ppm TBHQ (ULSBOW). The LLSBO and LLSBOW contained 11.1% palmitic acid, 5.0% stearic acid, 23.0% oleic acid, 58.7% linoleic acid, and 2.2% linolenic acid. The ULSBO and ULSBOW contained 11.4% palmitic acid, 5.0% stearic acid, 25.2% oleic acid, 57.4% linoleic acid, and 1.0% linolenic acid. For each of these four treatments, two bottles were retained at arrival, and half of the remaining bottles were stored under fluorescent light with uniform exposure of 70-footcandle light intensity at 21°C and the other half at 32°C, respectively, for 12 mon. Thus, there were eight treatments during storage. Duplicate bottles of oil from each treatment were analyzed in duplicate at 0, 2, 4, 6, 8, 10, and 12 mon of storage for flavor characteristics.

Chemical and other objective evaluation methods. A related paper presents complete information on the impact of 18:3 content, TBHQ addition, storage temperature and storage time on PV, oil stability index, *p*-anisidine value, polar compounds, and Lovibond colors, including statistical evaluations of the differences (9).

FA composition by GC. FA compositions of SBO were determined by converting TAG into FAME according to a method described by Hammond (10). The GC conditions were the same as described by Shen *et al*. (11).

Sensory evaluations. The sensory evaluations were conducted according to AOCS Recommended Practice Cg 2-83 (1) as described elsewhere (9).

Faces. Statistical software S-plus 6.0.3 Release 2 for Microsoft Windows was used to draw the faces (7). In this software, the facial features and their sequences are: 1-area of face; 2-shape of face; 3-length of nose; 4-location of mouth; 5-curve of smile; 6-width of mouth, and so on (Table 1). Thus, the area of the face represents the value of the first variable (flavor attribute, in this case); the shape of the face represents the second flavor attribute, and so on. The researcher can perform permutations by arranging the order of flavor attributes in the data table to get the best-represented data by the faces. Also, all facial features do not need to have a variable assigned. After several attempts of permutation to assign flavor attributes to different facial features, we decided on the correspondence between flavor attributes and facial features shown (Table 1). The range in the dimensions and/or shape of each facial feature was from 1 to 10, with 10 representing "excellent" and 1 representing "poor" for each of the flavor attributes. We chose not to assign an attribute to the length of the nose (dimension #3, Table 1), and to dimensions #7 through #15; thus, the computer program assumed the mid-value of 5 for these unassigned facial features. The numerical data supplied by the sensory panelists for each attribute were used by the statistical program to draw a face representing the sensory evaluation of a specific oil at a specific time. The data of all flavor attributes of a specific oil at a specific time, then, make up the "face" for that oil at that time.

The S-plus command was designated as follows: faces(as.matrix(faces1), labels=row.names(faces1), nrow=4, ncol=8). The term "faces" is the command to draw a face plot; "as.matrix" defines the data table to be used by faces command; "faces1" is the name of the data table to be used by the faces command; "labels= row.names(faces1)" means that each of the faces will be labeled by the row name of data table faces1; and "nrow=4, ncol=8" means there will be 4 rows and 8 columns of faces displayed on one page as shown in Figure 1.

Statistical analyses. The Pearson correlation coefficients between the intensity of individual flavors and overall flavor quality scores of SBO were calculated by using SAS software (12).

RESULTS AND DISCUSSION

Overall flavor quality. Initially, LLSBO and LLSBOW had better overall oil quality than did ULSBO and ULSBOW, respectively (data summarized in Table 2 from Ref. 9). The

TABLE 1
Correspondence Between the Assigned Facial Features and the Numerical Values Assigned to the Facial Features

Dimension	Facial features	Flavor attribute[a]	Numerical value assigned[b]
1	Area of face	Overall oil quality	1–10 from sensory data
2	Shape of face	Painty	1–10 from sensory data
3	Length of nose	—	5
4	Location of mouth	Grassy	1–10 from sensory data
5	Curve of smile	Fishy	1–10 from sensory data
6	Width of mouth	Beany	1–10 from sensory data
7	Location of eyes	—	5
8	Separation of eyes	—	5
9	Angle of eyes	—	5
10	Shape of eyes	—	5
11	Width of eyes	—	5
12	Location of pupil	—	5
13	Location of eyebrow	—	5
14	Angle of eyebrow	—	5
15	Width of eyebrow	—	5

[a]The sign "—" means no flavor attribute was assigned to that facial feature, and S-plus assumes a mid-value of "5" to that feature to draw a complete face.
[b]Values of 10 (excellent) to 1 (poor) were given to each flavor characteristic of oils, according to the panelists' scores.

FIG. 1. Faces representing the two extreme examples and the sensory characteristics of soybean oils (SBO) during storage. Excellent and poor examples are given in the first and last column. LL = SBO with low-linolenic acid (18:3); UL = SBO with ultra-low 18:3; Presence of W means SBO with 100 ppm TBHQ addition; The 0, 2, 4, 6, 8, 10, and 12 means SBO stored for 0 (fresh), 2, 4, 6, 8, 10, and 12 months, respectively; The 21 and 32 = storage temperature at 21°C and 32°C, respectively.

differences tended to reverse as storage progressed, with both UL treatments having better overall scores in later months of storage. This observation was consistent with the results for the PV of the oils (9). That is, when TBHQ was absent and at the same storage temperature, the ULSBO initially had significantly greater PV than did LLSBO. But the trend reversed during storage by 10 mon at 21°C and by 8 mon at 32°C (9). The TBHQ addition tended to have a negative effect on overall oil quality by sensory evaluations, especially through 8 mon of storage. By 10 and 12 mon, however, TBHQ addition tended to minimize the poor overall oil-quality scores, likely because of its ability to retard lipid oxidation (9). Generally, oils stored at 21°C had better overall flavor quality than did oils stored at 32°C with the same linolenic acid and TBHQ level, especially as storage time increased between 4 and 10 mon. The overall appearance of the faces in Figure 1 illustrates these quality differences at a glance.

Intensity of individual flavors. The individual flavors detected by panelists in oils included nutty, buttery, corny, beany, hydrogenated, burned, weedy, grassy, rubbery, melon, painty, fishy, bitter taste, astringency, rancid, and oxidized. The predominant attributes (i.e., those attributes detected by at least three panelists in one session for at least five sessions throughout the evaluation time) detected by panelists in the SBO included painty, fishy, grassy, beany, nutty, and buttery flavors. The Pearson correlation coefficients between the intensity of each of these flavors and overall flavor quality scores were 0.870, 0.731, 0.687, 0.681, 0.403, and 0.002, respectively. That is, the more intense (lower values) the flavors of painty, fishy, grassy and beany flavors, the poorer (lower) the overall flavor-quality scores in sensory evaluations. There were no correlations between the intensity of nutty and buttery flavors and overall flavor quality scores.

Faces. Each face in Figure 1 represents both the overall oil quality and the intensity of individual flavors of one oil treatment at a specific storage time. In other words, it is a highly condensed version of the data. The faces can be used to compare treatment impact on flavor characteristics of SBO. Initially, faces representing LLSBO were more "happy" and round than faces of ULSBO. The differences between the LL and UL SBO tended to disappear at about the 4-mon storage. The faces representing SBO with TBHQ addition were less "happy" than faces of SBO without TBHQ addition through 8 mon of storage, and this difference tended to disappear at 10-mon storage. Generally, faces of oils stored at 32°C were closer to "poor" than faces of oils stored at 21°C, and this difference became clearer at 8-mon storage.

The faces also can be used to detect, at a glance, the time point at which an individual SBO changed its multivariate sensory characteristics from relatively "excellent" to "poor." For example, initially, all the faces representing oils at arrival (0-mon storage) were very close to the excellent example. Even so, faces of ULSBO and ULSBOW were not as "happy" as the faces of LLSBO and LLSBOW. At 2-mon storage, faces were less round and began to develop features that were less "happy" than faces at 0-mon storage time. If the face of 4-LLSBOW32 (SBO with LL concentration, 100 ppm TBHQ addition, stored at 32°C for 4 mon) was viewed simply as an outlier, the 8-mon storage time seems to be when the faces began to turn "poor" as demonstrated by the consistently smaller, thinner, and longer face, the downward curvature of the smile, the longer distance between the nose and mouth, and the smaller width of the mouth. The faces at 6-mon storage were in transition from good to bad. By the end of 12-mon storage, all the faces of oils were very close to the "poor" example.

Both flavor quality scores and multiple individual flavors for the SBO represent typical multivariate data. The overall, combined sensory characteristics of SBO, however, represent an integrated perception. If the data of the intensity of all individual flavors were presented in the same way as the flavor quality

TABLE 2
Sensory Evaluation Scores[a] of Overall Quality of Soybean Oils

	Storage time (mon)						
Oils[b]	0	2	4	6	8	10	12
LLSBO21	8.4	7.5	7.5	5.5	5.2	4.9	3.2
ULSBO21	7.8	7.5	7.5	5.7	5.7	4.1	3.3
LLSBOW21	8.4	7.5	6.9	6.3	4.9	3.5	3.4
ULSBOW21	7.7	6.8	6.6	5.2	4.8	4.4	3.4
LLSBO32	8.4	7.2	6.2	5.1	4.2	3.6	3.3
ULSBO32	7.8	7.2	6.6	5.4	4.5	2.9	2.7
LLSBOW32	8.4	7.1	5.5	5.1	4.1	3.7	2.7
ULSBOW32	7.7	7.1	6.3	4.9	4.1	3.0	3.2
Comparison[c]							
LLSBO	8.4	7.3	6.5	5.5	4.6	3.1	3.1
ULSBO	7.7	7.1	6.8	5.3	4.8	3.6	3.2
W/O TBHQ	8.1	7.3	7.0	5.4	4.9	3.9	3.1
WTBHQ	8.0	7.1	6.3	5.4	4.5	3.7	3.1
21°C	8.1	7.4	7.1	5.7	5.1	4.2	3.3
32°C	8.1	7.1	6.1	5.1	4.2	3.3	3.0

[a]A score of 10 = excellent, a score of 1 = very poor (Ref. 1).
[b]LLSBO, low-linolenic acid soybean oil; ULSBO, ultra-low linolenic acid; presence of W = with TBHQ; absence of W = without TBHQ; 21 or 32 refers to storage temperature at 21 or 32°C.
[c]Comparison of the means at two levels of one treatment factor regardless of the levels of the other two factors.

scores in Table 2, one would need at least four more similar-sized tables. Repetitious viewing of large tables of data is tedious as described by the two 19th-century economists, Farquhar and Farquhar, "Getting information from a table is like extracting sunlight from a cucumber" (13). Thus, to improve data interpretation, the method of Chernoff faces was used to represent the multifactored changes of flavor characteristics of SBO during storage in a straight-forward pictorial display.

The method of using Chernoff faces in other applications has been criticized, because of the effect associated with a particular subjective facial feature; for example, curvature of the smile and/or other certain facial features may be more informative than other features (5,14–16). A wisely chosen featural assignment, however, limits this possibility. In our case, for example, the painty, fishy, and beany flavors, significant off-flavors associated with SBO flavor instability, were assigned to the shape of the face, curvature of the smile, and width of mouth, respectively, which have major impact on facial expressions. In other studies, where there are no major attributes, the assignment of a variable to a more informative facial feature can be avoided. Therefore, the permutation of the variable assignment to a facial feature, as performed in this application, is necessary to get the best data representation by the faces.

Finally, the disadvantage of subjectivity, which is sometimes noted when using Chernoff faces, actually may be an advantage when applied to sensory evaluation analyses. To the consumer, excellent sensory quality of a food product makes them "happy." This paper demonstrates the use of Chernoff faces as an effective procedure for researchers to simplify the presentation of sensory characteristics of edible oils and to obtain an integrated judgment of the overall flavor characteristics of SBO at a glance. People react quickly to faces; thus, we envision the popularity of using Chernoff faces in the sensory evaluation of a variety of food products, as well as other applications described by other authors (14).

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