Sensory Characteristics of Soymilk and Tofu Made from Lipoxygenase-Free and Normal Soybeans

A. V. Torres-Penaranda, C. A. Reitmeier, L. A. Wilson, W. R. Fehr, and J. M. Narvel

ABSTRACT

Soymilk made from lipoxygenase-free soybeans had less cooked beany aroma, less cooked beany flavor and less astringency and was rated darker and more yellow than that made from soybeans with normal lipoxygenase. Sensory descriptive panelists noted no differences between lipoxygenase-free and normal soybeans for milky flavor, wheat flavor, thickness, chalkiness or aftertaste. Tofu made from lipoxygenase-free soybeans had less cooked beany flavor than that made from normal soybeans. There were no differences in cooked beany aroma, raw beany aroma, raw beany flavor, wheat flavor, astringency, hardness, darkness or yellowness. Native-born Japanese, Chinese and U.S. descriptive panelists differed in responses to flavor, texture and color of soymilk and tofu.

Key Words: soymilk, tofu, flavor, lipoxygenase, soybean

INTRODUCTION

LIPOXYGENASES PRODUCE OFF-FLAVORS IN SOYBEANS [*GLYCINE max* (L.) Merr.] by hydroperoxidation of fatty acids and by interaction with protein in flours, concentrates and isolates (Rackis et al., 1979). The undesirable flavors, characterized as beany, green, grassy, painty, astringent, and bitter, reduce acceptance of soy products by many consumers who may prefer a bland flavor in soy products.

Normal mature soybean seeds contain three lipoxygenase isozymes important for flavor (SBL-1, SBL-2, and SBL-3) (Axelrod et al., 1981); other isozymes have been described in soybeans (Shibata, 1996). The three isozymes have been associated with the production of hexanal and other aldehydes, ketones and alcohols that contribute to off-flavor. Hexanal, an undesirable flavor compound of raw soybeans, is a breakdown product of the hydroperoxides produced from oxidation of linolenic and linoleic acids. Matoba et al. (1985) determined that the SBL-2 isozyme was responsible for n-hexanal formation by using free linoleic acid as the substrate and comparing soybeans lacking SBL-1, SBL-2, SBL-3, and SBL-1,3 isozymes. Furuta et al. (1996) reported that lipoxygenase-free soybeans had lower 1,3-diethyl-2-thibarbituric acid (an index for hydroperoxide production) and n-hexanal levels than soybeans with lipoxygenase or lacking SBL-1, SBL-2, or SBL-3 isozymes. Several researchers identified soybeans lacking one or more lipoxygenase isozymes (Hildebrand and Hymowitz, 1981; Kitamura et al., 1983; Kitamura et al.,1985; Davies and Nielsen,1986; Hajika et al., 1992). Hildebrand et al. (1990) noted that soybeans containing the SBL-3 isozyme had reduced hexanal formation.

Genetic removal of the lipoxygenase isozymes may reduce or eliminate off-flavors of soy and increase consumer acceptability in some markets. Removal of the SBL-2 isozyme produced lower scores for beany, rancid and oily flavor and aroma attributes in soymilk and soy flour and higher scores for dairy and cereal flavor and aroma (Davies et al., 1987). Soymilk made from soybeans lacking SBL-2,3 and SBL-1,2,3 had less volatiles including hexanal, 1-penten-3-ol, 2-hexenal, 2-pentylfuran, 1-pentanol, 2-pentanol, 2-heptanal, hexanol, nonanal, 1-octen-3-ol, and 2,4-decadienal (Kobayashi et al., 1995). According to Wilson (1995), the objectionable flavor and odor of soymilk are formed by oxidation of specific unsaturated fatty acids by lipoxygenase enzyme during grinding of the seed. Soymilk flavor has an impact on the sensory attributes of tofu since it is an intermediate product. Wilson (1996) reported that tofu made from lipoxygenase-2 null lines of soybeans were less beany than their respective controls as evaluated by a sensory panel.

U.S. consumers have been slow to accept soy in food products because of the off-flavors (Wilson, 1996). Development of soybean lines with less intense flavor characteristics may be useful in marketing food products to such consumers. But, there has been little evaluation of foods made with lipoxygenase-free lines of soybeans.

Cultural differences in consumption of soy products might account for some differences in perception of sensory attributes. Marketing of new soybean lines and soy products for export may require calibration of panels across cultures. The need for using sensory panelists from the targeted markets for successful product development has been pointed out by Hollingsworth (1998). Studies using panels from different countries to evaluate the same product may give some indication about whether such differences should be considered. Sensory panels from different countries have been used to determine whether the underlying perceptual dimensions characterizing samples of milk chocolate were stable across two different cultures (Risvik et al., 1992).

The objectives of this research were to compare soymilk and tofu made from normal and lipoxygenase-free soybeans, and to use three different panels equally trained to evaluate the products to indicate differences in sensory perception across cultures. Trained panelists from the United States, Japan or China evaluated 15 color, texture and flavor characteristics of soymilk and tofu.

MATERIALS & METHODS

Preparation of soymilk

Soybean lines homogeneous for the three alleles controlling normal lipoxygenase and lines homogeneous for the three null alleles controlling absence of the lipoxygenase were grown at the Agricultural Engineering & Agronomy Research Center of Iowa State Univ. during the summer of 1996. The BC1F2:4 lines were selected from a backcross population developed by the transfer of the three null alleles into the cultivar IA2020. The donor parent for the backcross was a lipoxygenase-free genotype obtained from Keisuke Kitamura at the National Agriculture Research Center, Yatabe, Tsubuka, Japan in 1992. The agronomic and seed traits of the soybean lines lacking seed lipoxygenase isozymes were described by Narvel et al. (1997).

Each line was harvested separately and 25 individual seeds of each were evaluated by a colorimetric assay (Suda et al., 1995) to confirm that the lines were homogeneous for presence or absence of the lipoxygenase alleles. To obtain sufficient seeds for the soymilk and tofu tests, it was necessary to combine the seeds of 7 normal or

Authors Torres-Penaranda, Reitmeier, and Wilson are affiliated with the Dept. of Food Science & Human Nutrition and authors Fehr and Narvel are with the Dept. of Agronomy, Iowa State Univ., Ames, IA 50011.

7 lipoxygenase-free lines. The seeds were stored at 4°C until the soymilk and tofu were processed. A sample (3.5 kg soybeans) was soaked with tap water at room temperature for 12h, drained, sorted to remove beans that were not hydrated, and washed with fresh water. The hydrated beans were combined with 26 kg tap water and ground twice with a Stephan grinder (A. Stephan u.Sohne GmbH & Co., West Germany). Soymilk was prepared from the slurry with an Automatic Soymilk Plant (Takai Tofu & Soymilk Equipment Co., Japan). The maximum temperature reached by the soymilk was 95°C. Soymilk was homogenized with a double-stage homogenizer (Gaulin Corporation, Everett, MA) and stored 18h at 4°C until evaluation.

Preparation of tofu

Tofu was made from soymilk prepared as described. A solution of calcium sulfate was added to soymilk at 80-82°C so the final concentration of coagulant was 0.02N. The soymilk and coagulant mixture was allowed to stand for 2 min for formation of curds. The resulting coagulum was cut and drained 5 min for separation of the whey. Curds were placed in a 43 × 49-cm perforated press box covered with cheese cloth and pressed with a hydraulic press. Pressure was applied three times for 5 min at 2 kg/cm^2, 5 min at 4 kg/cm^2, and 5 min at 6 kg/cm^2. Tofu was cooled to 20°C in a fresh water bath and 2.5 cm was trimmed from the edge of the tofu block. The remaining tofu was cut into 12.7 × 7.3-cm pieces. Only pieces from the outside of the block were sampled; pieces located in the four corners and the middle were not considered because of differences in firmness (Torres and Reitmeier, unpublished data). Tofu was stored in water-filled plastic containers at 4°C for 18h until texture evaluation and 48h until sensory evaluation.

Sensory evaluation

Sensory training and evaluation of soymilk were conducted in a 5-wk period followed by a 5-wk period of training and evaluation of tofu according to procedures described by Meilgaard et al. (1991). Soymilk or tofu samples were presented in partitioned booths for evaluation, under white light and at room temperature. Soymilk (30 mL) or tofu (15g) was presented in clear plastic cups labeled with 3-digit random numbers. Cups were covered with lids to avoid volatilization of aroma compounds. The samples were presented in a counterbalanced order. Samples from lipoxygenase-free soybeans were presented first. Two samples of tofu or soymilk were evaluated per session. Tofu blocks were steamed in a covered pan for 5 min and cut into 1-cm cube samples. Four cubes per cup were presented to panelists. The two samples (normal and lipoxygenase-free) of soymilk (or tofu) were evaluated with a 15-cm intensity linescale anchored from none to intense for each attribute. Judges were instructed to swallow the samples and rinse with water between samples. For aroma evaluation, judges smelled the samples in two short sniffs. Hardness of tofu was evaluated as the force required to masticate when the sample was put between molars. Thickness of soymilk was evaluated as the force to draw the sample between the lips from the spoon and the rate of flow across the tongue.

The sensory panel consisted of three groups of different native-born nationalities. In preliminary sessions, each group developed terminology to analyze the products. Separate sessions were conducted for each product. There were 12 U.S.-born judges, 11 Chinese-born judges, and 9 Japanese-born judges for soymilk evaluation (32 total) and 12 U.S.-born judges, 10 Chinese-born judges, and 7 Japanese-born judges for tofu evaluation (29 total). American judges were monolingual English speakers, Chinese were Chinese-English bilingual and Japanese were bilingual in Japanese and English. All judges were ISU graduate students educated in their language at the university level. Taste and aroma attributes were determined by presenting judges pilot-plant soymilk (or tofu) and asking for descriptors. The judges indicated those terms which they thought were present in the products. Also, a preliminary list of the terms most frequently reported and published, was selected by the researchers and presented to the judges to be considered as descriptors as well. The terms that were more frequently mentioned and discussed by the judges and that the panelists in the three groups agreed were appropriate to describe the products were selected. The same protocol was repeated for tofu evaluation.

After selection of the attributes, groups were trained separately, but by similar procedures and by the same person. Two 1-h training sessions were conducted for each group and for each of the two products. Groups were trained separately to give more attention to individuals and to avoid influence of one group to the other. The same protocol was repeated for tofu evaluation. The panelists were the same for tofu and soymilk except three panelists dropped out of the tofu evaluation.

Flavor attributes evaluated for both soymilk and tofu were cooked beany aroma, cooked beany flavor, raw beany aroma, raw beany flavor, milky flavor, wheat flavor, and astringency. The viscosity of soymilk was evaluated by thickness and the texture by chalkiness and aftertaste. Tofu samples were evaluated for hardness. Color attributes were yellowness and darkness for both soymilk and tofu.

Judges were presented with standards to identify maximum intensity (15 cm on the scorecard) for each attribute. Judges compared commercial and pilot plant-prepared soymilk (or tofu) samples. The standards were soymilk with lipoxygenase present and overheated at 97°C for 15 min for cooked beany aroma and cooked beany flavor, uncooked soymilk slurry with lipoxygenase present for raw beany aroma and raw beany flavor, whole dairy milk for milky flavor, 'Cream of Wheat' (Nabisco Inc, East Hanover, NJ) for wheat flavor, an alum solution (2 g/L) for astringency, 'Eden Soy Extra' Soymilk (Eden Foods, Inc., Clinton, MI) for darkness and aftertaste and eggnog (Borden Inc, Columbus, OH) for yellowness and thickness, and antacid tablets (Chateau, Chaska, MN) for chalkiness.

Statistical design and analysis

Data from soymilk and tofu evaluation were analyzed using Proc GLM (SAS Institute, Inc., 1988). One replicate of this experiment consisted of processing a batch of the product and having panelists evaluate the sensory properties. The Americans, Chinese and Japanese were represented by 12, 11 and 9 panelists respectively for soymilk evaluation (or 12, 10 and 7 for tofu). This protocol was repeated 3× for each product. An average value was determined for each line, nationality and replication. Resulting averages were used as data in a randomized complete block analysis where replications were blocks and six treatments were a factorial combination of two lines and three nationalities. When F values were significant ($p<0.05$), least significant differences (LSD) were calculated. Main effect means (line and panelist nationality) were reported when no interactions were present. Interaction means were reported when an interaction occurred between line and panelist nationality, i.e., for raw beany aroma and raw beany flavor of soymilk and milky flavor of tofu.

RESULTS & DISCUSSION

Effect of soybean type

Soymilk made from the lipoxygenase-free soybeans had less cooked beany aroma, less cooked beany flavor and less astringency than that from the normal line (Table 1). Sensory panelists reported low values for raw beany aroma (3.8) and raw beany flavor (4.6) and raw aroma and flavor were not expected to be strong in cooked soymilk samples. Less astringency was expected since the lipoxygenase enzymes may contribute such flavors (Rackis et al., 1979). Flavonoids and other phenolic compounds contribute astringency to soymilk. A concern that bland (lipoxygenase-free) soyfoods may allow the astringency to become more pronounced (Wilson, 1996) was not supported by our results.

There were no differences between lipoxygenase-free and normal soybeans for milky flavor, wheat flavor, thickness, chalkiness or aftertaste (Table 1). The similar genetic background of the soybean types, except for absence of lipoxygenases, was expected to yield products with similar characteristics other than beany flavor.

Table 1—Normal and lipoxygenase-free lines main effect sensory differences for soymilk[a]

Sensory attribute	Normal	Lipoxygenase-free	p-Value
Flavor			
Cooked beany aroma	7.3	5.4	<0.01
Cooked beany flavor	7.5	6.3	<0.01
Milky flavor	2.6	3.0	0.23
Wheat flavor	4.2	3.4	0.08
Astringency	4.6	3.7	0.04
Viscosity			
Thickness	3.1	3.5	0.09
Texture			
Chalkiness	2.3	2.0	0.17
Aftertaste	5.2	4.8	0.30
Color			
Darkness	3.9	5.4	<0.01
Yellowness	6.1	8.0	<0.01

[a]Main effect means are responses of 32 panelists and 3 replications.

Table 2—Normal and lipoxygenase-free lines main effect sensory differences for tofu[a]

Sensory attribute	Normal	Lipoxygenase-free	p-Value
Flavor			
Cooked beany aroma	7.3	6.5	0.27
Raw beany aroma	2.7	3.1	0.42
Cooked beany flavor	6.9	6.0	0.06
Raw beany flavor	2.5	2.4	0.76
Wheat flavor	3.7	3.3	0.24
Astringency	3.0	2.7	0.33
Texture			
Hardness	8.1	7.5	0.08
Color			
Darkness	2.9	3.3	0.14
Yellowness	5.1	5.6	0.53

[a]Main effect means are responses of 29 panelists and 3 replications.

Table 3—Significant sensory interaction effects of nationality of origin by line for soymilk and tofu[a]

	U.S.		Chinese		Japanese	
Sensory attribute	Normal	Lipoxy-genase-free	Normal	Lipoxy-genase-free	Normal	Lipoxy-genase-free
Soymilk						
Raw beany aroma	4.7c	2.7ab	2.0a	3.2b	5.4c	4.5c
Raw beany flavor	6.1d	4.1b	2.5a	4.2bc	5.3cd	5.5d
Tofu						
Milky flavor	2.0b	2.2b	0.1a	0.0a	4.3c	3.1b

[a]Interaction means (values within a row) are responses of 12 U.S., 11 Chinese and 9 Japanese panelists for soymilk and 12 U.S., 10 Chinese and 7 Japanese panelists for tofu in 3 replications. Means within a row followed by the same letter are not significantly different (p<0.05).

Table 4—Nationality of origin main effect sensory differences for intensity ratings of soymilk samples[a]

Sensory attribute	U.S.	Chinese	Japanese	p-Value
Flavor				
Cooked beany aroma	4.7b	7.2a	7.1a	<0.01
Cooked beany flavor	5.7b	7.7 a	7.4a	<0.01
Milky flavor	3.6a	1.1b	3.7 a	<0.01
Wheat flavor	4.0	3.6	3.9	0.72
Astringency	4.5a	3.2 b	4.7a	0.02
Viscosity				
Thickness	3.3	3.0	3.6	0.11
Texture				
Chalkiness	2.0b	1.3c	3.1a	<0.01
Aftertaste	5.0b	4.0c	6.1a	<0.01
Color				
Darkness	4.5b	4.3b	5.2a	0.01
Yellowness	7.8a	6.2b	7.1ab	0.02

[a]Main effect means are panelist responses for normal and lipoxygenase-free soybeans in 3 replications. Means within a row followed by the same letter are not significantly different (p<0.05).

Lipoxygenase-free soymilk was rated darker and more yellow by visual apperearance than soymilk made from normal soybeans (Table 1) although measurement of color by Hunter spectrocolorimeter indicated no differences between normal (L=83.50, a=1.45, b=10.28) and lipoxygenase-free (L=83.00, a=1.53, b= 11.59) soymilk.

Sensory panelists rated tofu from lipoxygenase-free soybeans had less (p=0.06) cooked beany flavor than that from the normal cultivar (Table 2). There were no differences between tofu samples in cooked beany aroma, raw beany aroma, raw beany flavor, wheat flavor, astringency, hardness, darkness or yellowness (Table 2). Hunter color values for normal (L=88.26, a=0.25, b=13.16) and lipoxygenase-free (L=88.71, a=0.31, b=13.53) soymilk were not different. Tofu generally has been perceived as milder in flavor than soymilk. Removal of the whey during the processing of tofu probably eliminates water-soluble compounds that contribute to flavor (Watanabe and Kishi, 1984); however, no studies have identified such flavor compounds that are removed.

An interaction occurred between soybean cultivar and panelist nationality for raw beany aroma and raw beany flavor of soymilk (Table 3). U.S. panelists rated the soymilk from lipoxygenase-free soybeans as having less raw beany aroma than that from normal soybeans. Chinese panelists rated the soymilk from lipoxygenase-free beans with more raw beany aroma than the soymilk from the normal line. For raw beany flavor, U.S. panelists found less intense flavor in the soymilk made from lipoxygenase-free soybeans, Chinese panelists found more flavor and the Japanese panelists found no differences. The low intensity of the raw aroma and flavor would make differentiation between soymilk from normal and lipoxygenase-free soybeans difficult.

Effect of panelist nationality

Results indicated that panelists were using different parts of the linescale to evaluate soymilk and tofu from normal and lipoxygenase-free soybeans. They responded similarly to the normal and lipoxygenase-free soymilk (i.e., there was no interaction between soybean type and panelist type), except for raw beany aroma and raw beany flavor (Table 3). For cooked beany aroma and flavor of soymilk, Chinese and Japanese panelists used the rating scale similarly and higher than U.S. panelists (Table 4). Japanese panelists rated soymilk higher than or equal to U.S. panelists in milky flavor, astringency, chalkiness and aftertaste. Both Japanese and U.S. panelists rated these soymilk characteristics higher than did the Chinese panelists. Japanese panelists rated the soymilk darker than did the U.S. and Chinese panelists. For yellow color of soymilk, U.S. and Japanese ratings were similar and Japanese and Chinese ratings were the same. Panelists were not different in ratings of soymilk for wheat flavor or thickness.

Japanese panelists rated raw beany aroma and raw beany flavor of tofu higher than U.S. panelists; the Chinese responses were the same as the U.S. for raw beany aroma, but less than the U.S. responses for raw beany flavor (Table 5). Cooked beany aroma responses were not different. Chinese and Japanese panelists were similar in response to cooked beany flavor whereas U.S. panelists scores were less than the Japanese but the same as the Chinese scores.

Japanese scores were the same or greater than U.S. responses for wheat flavor and astringency and the Chinese responses were lower than the U.S. (Table 5). Hardness of the tofu was scored highest by the Chinese, followed by the Japanese, then the U.S. Japanese consumers usually eat pasteurized and refrigerated silken tofu that is soft and includes the whey; U. S. consumers prefer a smooth, cheese-like texture for tofu (Murphy et al., 1997). The U.S. panelists gave

Table 5—Nationality of origin main effect sensory differences for intensity ratings of tofu samples[a]

Sensory attribute	American	Chinese	Japanese	p-value
Flavor				
Cooked beany aroma	6.0	7.2	7.6	0.17
Raw beany aroma	2.7b	1.7b	4.4a	<0.01
Cooked beany flavor	5.5b	7.3a	6.5ab	0.02
Raw beany flavor	2.4b	0.7c	4.2a	<0.01
Wheat flavor	3.7a	2.9b	3.9a	0.03
Astringency	3.3b	1.0c	4.2a	<0.01
Texture				
Hardness	6.0c	9.0a	8.3b	<0.01
Color				
Darkness	4.0a	3.0b	2.2c	<0.01
Yellowness	5.6	5.0	5.5	0.83

[a]Main effect means are panelist responses for normal and lipoxygenase-free soybeans and 3 replications. Means within a row followed by the same letter are not significantly different (p<0.05).

higher values for darkness than did the Chinese and the Japanese. There was no difference in responses to tofu yellowness.

An interaction occurred between soybean type and panelist nationality for milky flavor characteristic of tofu (Table 3). The U.S. and Chinese found no difference between tofu from normal beans and that from lipoxygenase-free beans, but the Japanese rated the tofu from lipoxygenase-free beans as having less milky flavor than that from normal beans.

Responses of the Japanese to sensory characteristics of soymilk and tofu generally were higher than the responses of U.S. panelists. Chinese panelists rated the soy products lower in flavor intensity than U.S. panelists. There was some concern that Japanese consumers of traditional soyfoods such as soymilk and tofu may find the products without lipoxygenase too bland (Wilson, 1996). The intensity of flavors, except cooked beany flavor, did not decrease notably in the lipoxygenase-free soy products.

The term beany has been extensively used concerning evaluation of soy products. Use of this term may be inappropiate since it is complex and has different meaning for people from different cultures. The use of a single standard for beany may not be valid. The use of more specific terms may be necessary to align the beany concept within and among panels. As Ishii and O'Mahony (1987) indicate, the use of several standard stimuli may be necessary for definition of a taste concept. More extensive descriptive analysis for the attributes related to beany assessment may be necessary to more effectively describe this term. Investigation on the use of flavor profile methodology to describe beaniness of soy products is needed.

CONCLUSIONS

THERE WAS A REDUCTION IN COOKED BEANY AROMA AND FLAvor of soymilk and tofu made with soybeans without the SBL-1, SBL-2, and SBL-3 lipoxygenase isozymes. Cultural differences may have accounted for some of the variations in panelist responses by nationality. Cultural differences in response to soy products may exist and should be considered when marketing lipoxygenase-free soybean products.

REFERENCES

Axelrod, B., Cheesbrough, T.M., and Laakso, S. 1981. Lipoxygenase from soybeans. Methods Enzymol. 71: 441-451.

Davies, C.S. and Nielsen, N.C. 1986. Genetic analysis of a null-allele for lipoxygenase-2 in soybean. Crop Sci. 26: 460-463.

Davies, C.S., Nielsen, S.S., and Nielsen, N.C. 1987. Flavor improvement of soybean preparations by genetic removal of lipoxygenase-2. J. Amer. Oil Chem. Soc. 64(10): 1428-1433.

Furuta, S., Nishiba, Y., Hajika, M., Igita, K., and Suda, I. 1996. DETBA value and hexanal production with the combination of unsaturated fatty acids and extracts prepared from soybean seeds lacking two or three lipoxygenase isozymes. J. Agric. Food Chem. 44: 236-239.

Hajika, M., Kitamura, K., Igita, K., and Nakazawa, Y. 1992. Genetic relationships among the genes for lipoxygenase 1-, 2- and -3 isozymes in soybean [Glycine max (L.) Merrill] seed. Jpn. J. Breed. 42: 787-792.

Hildebrand, D.F. and Hymowitz, T. 1981. Two soybean genotypes lacking lipoxygenase-1. J.Amer. Oil Chem. Soc. 58: 583-586.

Hildebrand, D.F., Hamilton-Kemp, T.R., Loughrin, J.H., Ali, K., and Andersen, R.A. 1990. Lipoxygenase-3 reduced hexanal production from soybean seed homogenates. J. Agric. Food Chem. 38: 1934-1936.

Hollingsworth, P. 1998. Sensory testing rediscovered as key to new product success. Food Technol. 52(4): 26-27.

Ishii, R. and O'Mahony, M. 1987. Taste sorting and naming: Can taste concepts be misrepresented by traditional psychophysical labelling systems?. Chemical Senses. 12: 37-51.

Kitamura, K., Davies, C.S., Kaizuma, N., and Nielsen, N.C. 1983. Genetic analysis of a null-allele for lipoxygenase-3 in soybean seeds. Crop Sci. 23: 924-927.

Kitamura, K., and Kumagai, T., and Kikuchi, A. 1985. Inheritance of lipoxygenase-2 and genetic relationships among genes for lipoxygenase-1, -2, and -3 isozymes in soybean seeds. Jpn. J. Breed. 35: 413-420.

Kobayashi, A., Tsuda, Y., Hirata, N., Kubota, K., and Kitamura, K. 1995. Aroma constituents of soybean [Glycine max (L.) Merrill] milk lacking lipoxygenase isozymes. J. Agric. Food Chem. 43: 2449-2452.

Matoba, T., Hidaka, H., Narita, H., Kitamura, K., Kaizuma, N., and Kito, M. 1985. Lipoxygenase-2 isozyme is responsible for generation of n-hexanal in soybean homogenate. J. Agric. Food Chem. 33: 852-855.

Meilgaard, M., Civille, G.V., and Carr, B.T. 1991. Sensory Evaluation Techniques. 2nd ed. CRC Press, Inc., Boca Raton, FL.

Murphy, P.A., Chen, H.-P., Hauck, C.C., and Wilson, L.A. 1997. Soybean protein composition and tofu quality. Food Technol. 51(3): 86-88, 110.

Narvel, J.M., Fehr, W.R., and Welke, G.A. 1997. Agronomic and seed traits of soybean lines lacking seed lipoxygenase isozymes. Crop Sci. Submitted.

Rackis, J.J., Sessa, D.J., and Honig, D.H. 1979. Flavor problems of vegetable food proteins. J. Amer. Oil Chem. Soc. 56: 262-271.

Risvik, E. et al. 1992. Multivariate analysis of conventional profiling data: a comparison of a British and a Norwegian trained panel. J. Sensory Studies 7: 97-118.

SAS Institute, Inc. 1988. SAS/STAT User's Guide. Version 6.03, third ed. SAS Institute, Inc., Cary, NC.

Shibata, D. 1996. Plant lipoxygenase genes. Ch. 3 in Lipoxygenase Enzymes and Lipoxygenase Pathway Enzymes, G. Piazza (Ed.), p. 39-56. AOCS Press, Champaign, IL.

Suda, I., Hajiki, M., Nishibi, Y. Furuta, S., and Kazunori, I. 1995. Simple and rapid method for the selective detection of individual lipoxygenase isozymes in soybean seeds. J. Agric. Food Chem. 43: 742-747.

Watanabe, T. and Kishi, A. 1984. The Book of Soybeans. Japan Publications Inc., Tokyo and New York.

Wilson, L.A. 1996. Comparison of lipoxygenase-null and lipoxygenase containing soybeans for foods. Ch. 12. in Lipoxygenase Enzymes and Lipoxygenase Pathway Enzymes, G. Piazza (Ed.), p. 209-225. AOCS Press, Champaign, IL.

Wilson, L.A. 1995. Soy Foods. Ch. 22. in Practical Handbook of Soybean Processing and Utilization, D.R. Erickson (ED), p. 428-459. AOCS Press, Champaign, IL.

Ms received 10/26/97; revised 5/6/98; accepted 7/15/98.

Journal Paper No. J-17625 of the Iowa Agriculture and Home Economics Experiment Station, Ames, IA, Project Nos. 3362 and 3107 supported by Hatch Act funds. We also acknowledge financial support from the State of Iowa, the Iowa Soybean Promotion Board, and the Center for Crops Utilization Research, Iowa State University for production and sensory evaluation facilities.