Characterization of Corn-Soy Breakfast Cereals by Generalized Procrustes Analyses

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ABSTRACT

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Understanding the quality of products containing a substantial amount of soy protein is essential to meet the demand for soy foods that are acceptable to American consumers. In this study, the effects of sugar and feed moisture contents on the sensory characteristics of extruded corn-soy breakfast cereals were investigated, and the relationships among the product sensory and physical properties and extruder system responses were characterized by generalized procrustes analysis (GPA). Corn meal-soy protein isolate mixes were extruded at feed moistures of 21, 23, and 25% and sugar levels of 0, 5, and 10%. Descriptive sensory attributes, physical properties, and extruder responses were measured. GPA results showed that the breakfast cereal sensory attributes were primarily affected by the sugar-addition level. Products with sugar added at the 5% level were associated with soy and off-flavors, but increasing sugar to 10% yielded an association with crunchiness and hardness. Feed moisture content had a dramatic effect within the 5% added sugar products in determining sensory characteristics. Reverse relationships between mechanical system responses and sensory texture attributes were revealed by GPA results. Increased heat and mechanical forces in the extruder barrel were responsible for higher sensory residual soy flavor and off-flavor intensities.

Soy flour, soy proteins, or soy fiber have been added to corn or wheat grains to improve protein quality, especially for third world countries, or to provide dietary fiber (Camire and King 1991; Faller et al, *in press*; Molina et al 1983). Furthermore, recent scientific findings about anticarcinogenic, cholesterol-lowering, and anticalcium depletion effects of soy proteins and isoflavones (Anderson et al 1995, Erdman 1995) are encouraging consumers to incorporate soy proteins into their normal diets. In a survey of consumer attitudes and viewpoints about nutraceutical foods, 70% of respondents believed that certain foods can actually prevent disease and were willing to change their dietary patterns accordingly (Wrick et al 1993). Also, most of the respondents showed a positive reaction to the concept that food can be designed to deliver health benefits. However, soy-based food products appealing to American consumers are currently lacking in the marketplace. Klein et al (1995) emphasized the importance of developing acceptable soy-based products that can be incorporated into Americans' normal diets to provide the health benefits from soy proteins.

Extrusion is the technology used most often in the manufacture of ready-to-eat breakfast cereals because of its capability in handling raw ingredients and its processing conditions (Guy and Horne 1988). The sensory and physical properties of extrudates are affected by various conditions, such as feed moisture content and feed composition, and by the resultant modification of the extrusion processing environment, such as screw speed (Guy and Horne 1988; Chen et al 1991; Onwulata and Heymann 1994; Faller and Heymann 1996; Faller et al, *in press*;). Potato extrudates processed at high feed moisture content were characterized as high in light color, crispness, chewiness, and hardness but low in brown color, burnt flavor, and fracturability (Faller and Heymann 1996). Onwulata and Heymann (1994) reported that product color, density, breaking strength, and perceived adhesiveness were directly influenced by product and die temperatures, while radial expansion and perceived crispness were affected by torque and die pressure.

Recent studies have revealed that the addition of small amounts of functional ingredients such as sugar, salt, lipids, emulsifiers, dietary fibers, gums, and leavening agents result in the significant modification of processing parameters during extrusion, leading to significant variations in final product quality (Hsieh et al 1990, Moore et al 1990, Hsieh et al 1993, Jin et al 1994, Faller and Heymann 1996, Hu et al 1996). Although sugar is added primarily to provide sweet taste and browning reaction flavors, the presence of sugar in a dough melt alters the characteristics of final products because of the required modification of environmental settings during extrusion processing. Motor torque, die pressure, and specific mechanical energy decreased for 4 and 8% sugar addition for rice extrudates (Hsieh et al 1993) but increased for corn meal samples (Hsieh et al 1990). Inconsistent trends in breaking strength by adding 3–8% sugar were observed by Hsieh et al (1990), Hsieh et al (1993), and Moore et al (1990) for extrudates made with various cereal grains under differing extrusion conditions. Consequently, the effects of sugar in extrusion responses and the physical properties of the extrudates appear to be influenced by raw materials and processing conditions. Therefore, more extensive studies on the effect of sugar on processing responses and product quality are required. Sensory characteristics of extrudates containing sugar are essential to understanding the effect of sugar on the quality of ready-to-eat cereal. This knowledge will help to develop acceptable corn-soy breakfast cereals containing substantial amounts of soy protein.

The objectives of this study were: 1) to investigate the effects of sugar and feed moisture contents on the sensory characteristics of corn-soy extruded breakfast cereals, and 2) to reveal the relationship of product sensory attributes and physical properties to extrusion system responses by using the generalized procrustes multivariate analysis technique.

MATERIAL AND METHODS

Experimental Design and Data Analysis

A 3 × 3 factorial experiment with sugar level (0, 5, and 10%, w/w, of flour mix) and feed moisture content (21, 23, and 25%, w/w, of flour mix) was used for sample preparation; the extrusion operation was conducted twice for each treatment. Each extruder replicate was completely randomized, and both were conducted on the same day. Randomized complete block designs were used for analyzing sensory data, physical properties, and extrusion system responses. Forty data sets for sensory evaluation were obtained from 10 panelists and four replicates. Two sensory replicates were obtained from the samples of one extrusion replicate (e.g., sensory replicates 1 and 3 were from samples from extrusion replicate 1). The sensory data were submitted to the generalized procrustes analysis (GPA) procedure by using Gower's algorithm in Senstools (Oliemans and Punter 1997). This was done to characterize sample attributes and to reveal the intercorrelations among multiple attributes. Data

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from sensory evaluations averaged across panelists and replicates and physical measurements and extrusion responses averaged across replicates were also analyzed with the GPA procedure to discover the relationships among sensory characteristics, instrumental properties, and extrusion system responses.

Sample Preparation

Supro 670 isolated soy protein (22.2%, by weight, of flour mix) (Protein Technologies, St. Louis, MO) was mixed with corn meal (73.8, 68.8, and 63.8%, by weight, of flour mix) (Lauhoff, Danville, IL) and sugar (0, 5, and 10%, by weight, of flour mix) (Domino Sugar, New York, NY). Locally purchased wheat bran (4%, by weight, of flour mix) and salt (0.5%, by weight, of flour mix) (Morton Salt, Chicago, IL) were added to the flour mix. Products were extruded with a twin-screw extruder (model ZSK-30, Krupp, Werner and Pfleiderer, Ramsey, NJ) at 200 rpm screw speed, 13.6 kg/hr feed rate, and barrel zone temperatures of 60, 80, 120, 120, and 140°C from feed to die. A die with dual orifices (openings 4 mm in diameter and lengths of 4 mm) was used. Extrudates were pelletized at 390 rpm, and then 100 g of extrudate was coated with 20 g of a sugar solution containing 74% powdered sugar (Domino Sugar) and baked at 325°C for 8 min in a conveyer oven (model 1302, Impinger, Lincoln Foodservice Equipment, Fort Wayne, IN). The product was packaged in oxygen- and moisture-impermeable polyethylene pouches (15 g per pouch) (Kapak, St. Paul, MN), sealed with a Scotchpak heat sealer (Kapak), and stored at −40°C before testing.

Descriptive Sensory Evaluation

Ten panelists, who had participated previously in descriptive sensory tests with soy-based products and were students and staff of the University of Illinois, were trained for 12 hr to develop and standardize the test procedures. The intensities of 19 sensory attributes were evaluated on a 15-cm unstructured line scale with word anchors at both ends (0 = none to 15 = extreme). The definitions and evaluation procedures of selected sensory attributes are shown in Table I. Samples (10 g) were evaluated before (dry) and after (wet) the addition of 100 mL of skim milk (Prairie Farms, Peoria, IL). Warm and cold purified water (Polar Products, Decatur, IL) and fresh white bread were provided to clean the palate between sample evaluations to minimize the carryover effect.

Extruder System Responses and Physical Properties

Extruder motor torque, die temperature, and die pressure were recorded. Diameters of 10 pieces were measured with a caliper and averaged for each treatment. The product specific volume was determined by the rapeseed displacement method (Park 1976). *L* (lightness), *a* (redness), and *b* (yellowness) values were determined with a colorimeter (Hunter Associates, Reston, VA) on ground samples. Each test was conducted three times.

RESULTS AND DISCUSSION

GPA of Sensory Characteristics

GPA, which takes into account individual differences in scale use and terminology interpretation among panelists (Arnold and Williams 1986), showed that the first two dimensions accounted for 88.8% of the total variance across nine samples, 19 attributes, 10 panelists, and four replicates. The amount of total variance was above the 99% confidence interval criteria suggested by King and Arents (1991). Therefore, GPA results truly summarized the sensory characteristics of the samples, the relationships among the attributes, and the variations among panelists.

The two-dimensional GPA consensus plot for breakfast cereal samples (Fig. 1) showed that sugar content was responsible mainly for the clustering of samples on the first dimension. Feed mois-

TABLE I
Test Procedures Used for the Descriptive Sensory Evaluation of Corn-Soy Breakfast Cereals

Sensory Attribute	Abbreviation	Definition
I. Dry sample characteristics		
Step 1: Look at the samples in a bowl under the red light condition and evaluate the following:		
Expansion	expand	Degree of expansion in terms of the volume of a piece
Surface smoothness	smooth	Degree to which the surface is even or smooth
Step 2: Masticate a spoonful of the samples and evaluate the following:		
Hardness	dryhard	Degree of the force required for cutting samples
Crunchiness	drycrunch	Degree of snap, as measured by noise, force, and denseness, released from the sample
Adhesiveness	dryadhe	Degree to which the mass sticks to teeth
Toasted corn flavor	drycorn	Intensity of toasted corn flavor
Toasted soy flavor	drysoy	Intensity of toasted soy flavor
Sweetness	drysweet	Intensity of sweet taste
II. Bowl life (wet sample) characteristics		
Step 3: Pour milk in the bowl and stir samples a few times. Put a spoonful of the samples with milk in your mouth and evaluate the following:		
Initial Hardness	wethard1	Degree of the force required for cutting sample
Denseness	wetdense	Compactness of cross section of sample after biting completely through with the molars
Toasted corn flavor	wetcorn	Intensity of toasted corn flavor
Toasted soy flavor	wetsoy	Intensity of toasted soy flavor
Sweetness	wetsweet	Intensity of sweet taste
Step 4: Wait 3 min after pouring milk into the bowl. Take another spoonful of the samples with milk and evaluate the following:		
Wet hardness	wethard2	Degree of the force required for cutting samples
Crunchiness	wetcrunch	Degree of snap, as measured by noise, force, and denseness, released from the sample
Moisture absorption	wetmoisab	Amount of moisture absorbed by the sample
Adhesiveness	wetadhe	Degree to which the mass sticks to teeth
Step 5: Swallow samples and evaluate the following:		
Residual soy flavor	residualsoy	Intensity of toasted soy flavor left after swallowing
Off-flavor	off-flavor	Intensity of unpleasant and unexpected residual flavor in the mouth

ture content played a role only in association with low sugar content on the second dimension. As a result, three sample clusters formed on the two-dimensional space: 0% sugar at 21% feed moisture content and 5% sugar at 21 and 23% feed moisture content (group I); 0% sugar at 23 and 25% feed moisture content (group II); and 5% sugar at 25% feed moisture content and 10% sugar at all feed moisture contents (group III). The pattern of sample clusters provides support for the theory that sugar addition has two opposing effects: 1) preferential water binding of added sugar over starch and 2) liquefaction of sugar leading to a lubricating effect during extrusion processing and plasticization of the starch polymer. Moore et al (1990) and Sterling (1978) suggested that water activity or available water would be decreased in cooked dough with increased sucrose because of the preferential hydration of sugar over that of starch. In our study, samples containing 5% sugar at 21 and 23% feed moisture contents were similar in appearance to the sample with 0% sugar at 21% feed moisture content. Therefore, the small amount of added sugar (which might bind to water first) in a sample with low feed moisture content results in a low-moisture environment.

However, Meuser and Wiedmann (1989) reported that high levels of added sugar reduced melt viscosity and consequently resulted in reduced mechanical forces and dough temperature in the extruder barrel, suggesting liquefaction of sugar in the feed, which then acts as a lubricating agent. In our study, significant decreases in motor torque, die pressure, and die temperature at 5% sugar with 25% feed moisture and 10% sugar at all levels of feed moisture supported the liquefaction effect of added sugar. In the 25% feed moisture environment, 5% added sugar might liquefy the dough after being fully hydrated and thus lubricate the melt flow just as sugar at the 10% level did. Therefore, the small amount of added sugar played a critical role in determining sensory characteristics of final products.

The first dimension was highly positively loaded with expansion and moisture absorption but negatively loaded with hardness, crunchiness, and denseness of dry and wet samples (Fig. 2). The second dimension was loaded with corn, soy, and off-flavor. Therefore, the first and second dimensions could be represented as texture/puffing and flavor dimensions, respectively. Texture attributes and expansion were the dominant parameters in differentiating the sample characteristics containing variable amounts of sugar and feed moisture. The closeness of the dry and wet attributes indicates that the samples kept their integrity in milk. Expansion and moisture absorption attributes were highly positively correlated with each other but negatively correlated with surface texture and the initial and masticatory texture attributes of dry and wet samples. Therefore, the more expanded products absorbed more moisture when chewed but had lower surface smoothness, hardness, crunchiness, denseness, and sweetness. A negative correlation between degree of expansion and hardness-crispness for potato and corn extrudates was also reported by Faller and Heymann (1996) and Onwulata and Heymann (1994) from descriptive sensory tests. On the second dimension, soy flavors for dry and wet samples were highly associated with off-flavor but negatively correlated with corn flavors.

When sample and attribute consensus plots (Figs. 1 and 2) are superimposed, samples in group I (limited moisture during extrusion) could be characterized as more adhesive for the dry sample, stronger soy flavor for dry and wet samples, and stronger residual soy flavor and off-flavor. The elevated die temperature and mechanical forces present under the low-moisture conditions during processing probably contributed more to the characteristic flavor formation and overcooked residual flavors. In addition, the presence of sugar with soy proteins may have led to enhanced Maillard browning reactions, resulting in more flavor formation in these samples. Group II samples were more expanded and absorbed more moisture during chewing. Group III samples, which had the highest amount of sugar, were sweeter, smoother, harder, crunchier, and denser for both dry and wet samples. Sugar, acting as a plasticizer to starch polymers in the dough melt, resulted in lower expansion as well as more shrinkage of the extrudates upon cooling. In addition, liquefied sugar, acting as a lubricant in the extruder, resulted in low die temperature, leading to lower expansion. Increased apparent density and decreased physical expansion were also reported by Guy and Horne (1988), Jin et al (1994), and Moore et al (1990) with added sugar and salt.

The panelist coordinates for 10 panelists and four replicates (Fig. 3) were clustered by sensory replicates 1 and 3 and sensory replicates 2 and 4; each cluster was from the same extrusion processing replicate. Therefore, the variations in the sensory data were caused mainly by samples rather than by panelists. The panelists were well trained, as shown by their consistent performance within the same sample batch and their ability to discern differences between sample batches. Along with the close positions among panelists on the space, the small and even distribution of residual values for each panelist (0.95 ± 0.060) also supports the conclusion that they reached good agreement among themselves. The two circled panelists deviated from the rest of the panelists for the replicates indicated. However, their residual values were not much greater than those of

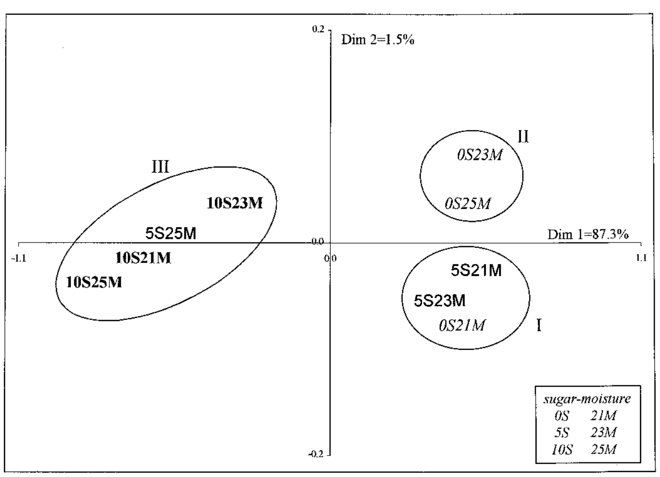

Fig. 1. Generalized procrustes analysis (GPA) sample consensus plot for sensory evaluation of corn-soy breakfast cereals containing 0, 5, and 10% sugar levels and processed at 21, 23, and 25% feed moisture contents across 19 attributes, 10 panelists, and four replicates. Dimension 1 accounted for 87.3% of the GPA variances, and dimension 2 accounted for 1.5%.

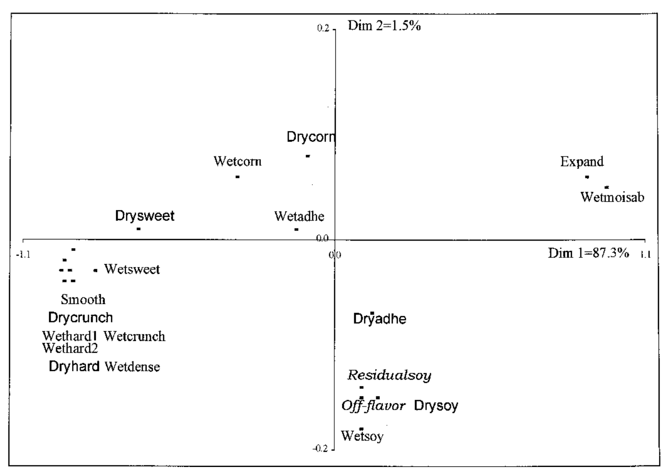

Fig. 2. Generalized procrustes analysis (GPA) attribute consensus plot for sensory evaluation of corn-soy breakfast cereals containing 0, 5, and 10% sugar levels and processed at 21, 23, and 25% feed moisture contents across nine samples, 10 panelists, and four replicates. Dimension 1 accounted for 87.3% of the GPA variances, and dimension 2 accounted for 1.5%. See Table I for attribute descriptions.

the others, so they were not considered outliers and were left in the analysis.

Relationship Between Sensory Characteristics and Mechanical Properties

Since different units are used to describe sensory responses and physical and mechanical measurements, it is suitable to use the GPA analysis with a prescaling mechanic, which allows one to adjust for scale discrepancies in data sets (Oreskovich et al 1992). GPA results show that data from extrusion system responses such as motor torque, die pressure, and die temperature were shrunken, while sensory evaluation and physical property data were stretched in order to calibrate scale differences among them. The total variance accounted for in the data set was 85.8%, which is well above the 99% significance level (King and Arents 1991). The first dimension extracted 80.8% of the variances in the data, indicating that the sensory data agreed with the extrusion system responses and physical product properties. The GPA attribute consensus plot (Fig. 4) showed an explicit association between processing conditions and product properties. All the extruder system responses were clustered together, indicating that the experimental variables have similar influence on the processing responses. However, in the principal component analysis for corn meal extrudates, Onwulata and Heymann (1994) found that die temperature response was different from that of motor torque and die pressure for corn extrudates. This discrepancy in the relationship between the variables might result from the differences in ingredient and processing conditions as well as the data-analysis mechanics. Unfortunately, no other references are available for confirming the relationships among these variables.

Extruder responses were directly positively related to residual soy flavor and off-flavor and moderately associated with Hunter *a* value (redness), diameter, and expansion properties. Residual soy flavor and off-flavor were highly correlated with Hunter *a* value (redness) and negatively correlated with Hunter *b* (yellowness) and *L* (lightness) values, indicating excessive cooking of products. Physical diameter and specific volume corresponded to sensory expansion rate and moisture absorption attributes but negatively correlated with sensory texture and flavor characteristics. These properties did not show much association with residual flavor attributes. A strong correlation between Hunter *a* value and die temperature and a negative correlation between expansion and texture attributes were also found for extrusion of potato puffs (Onwulata and Heymann 1994, Faller and Heymann 1996). Consequently, extreme temperature and mechanical force during processing were responsible for puffing properties as well as for unpleasant residual flavors caused by overcooking of the breakfast cereals.

Sample data were spread according to sugar level on the first dimension and according to moisture content on the second dimension over the GPA sample consensus space for sensory attributes, physical properties, and system response variables (Fig. 5). The results were similar to the sensory evaluation solutions. However, feed moisture content seemed to have more impact on sample positions after accounting for mechanical responses and physical properties than when sensory data was used alone (compare Figs. 1 and 5). Samples containing 0% sugar at all feed moisture contents had higher expansion rates, as measured by the sensory and instrumental tests, while samples with 5% sugar at low and medium feed moisture contents had more adhesiveness and stronger residual soy flavor and off-flavor characteristics. Samples with high levels of sugar were high in texture and flavor intensities for dry and wet samples. Therefore, addition of 5% sugar in association with low to medium feed moisture contents generated higher mechanical responses during processing because of the preferential hydration of sugar over starches, as reported by Moore et al (1990), and was responsible for the residual flavors in the sample.

CONCLUSIONS

The addition of 5 and 10% sugar to corn meal and soy protein isolate mix greatly affected extruder responses, sensory attributes and physical properties of extruded breakfast cereals. Feed moisture content was critical only with 5% added sugar and affected processing conditions and product qualities. Samples with high levels of added sugar had stronger corn flavor with less soy flavor and were sweeter, harder, crunchier, and denser before and after the addition of milk. High-temperature and high-shear processing conditions generated by adding 5% sugar at lower feed moisture content were associated with higher redness and stronger perceived residual soy flavor and off-flavor. GPA results revealed explicit associations among extruder responses, product physical properties, and sensory characteristics. It is recommended that less heat and mechanical force be applied during processing to avoid development of residual flavors.

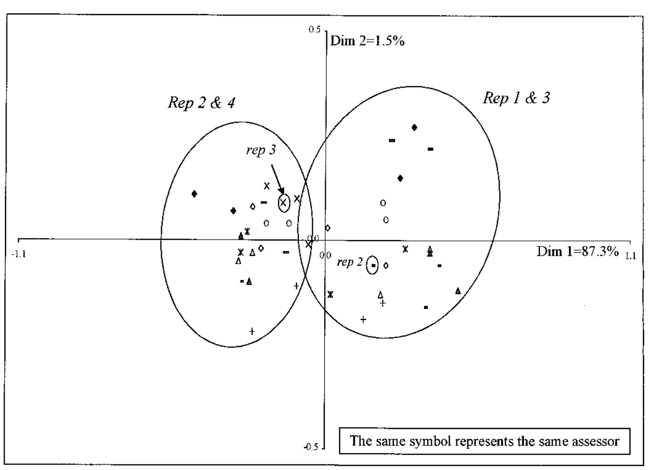

Fig. 3. Generalized procrustes analysis (GPA) assessor plot for sensory evaluation of corn-soy breakfast cereals containing 0, 5, and 10% sugar levels and processed at 21, 23, and 25% feed moisture contents across nine samples and 19 attributes. Dimension 1 accounted for 87.3% of the GPA variances, and dimension 2 accounted for 1.5%. Each symbol corresponds to one panelist.

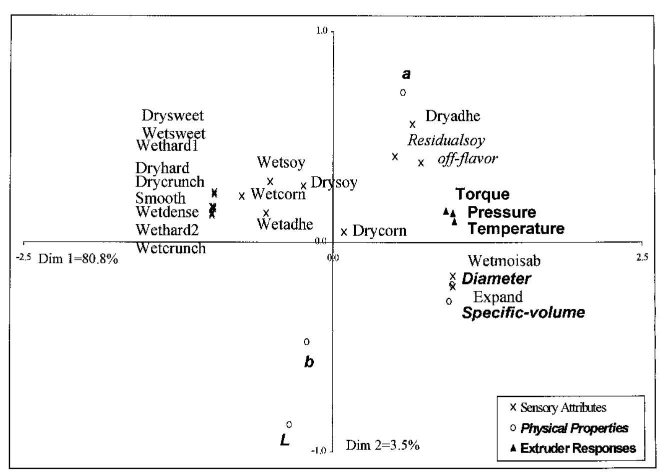

Fig. 4. Generalized procrustes analysis (GPA) attribute consensus plot for sensory data combined with physical properties and extrusion processing responses of corn-soy breakfast cereals containing 0, 5, and 10% sugar levels and processed at 21, 23, and 25% feed moisture contents. Dimension 1 accounted for 80.8% of the GPA variances, and dimension 2 accounted for 3.5%. See Table I for attribute descriptions.

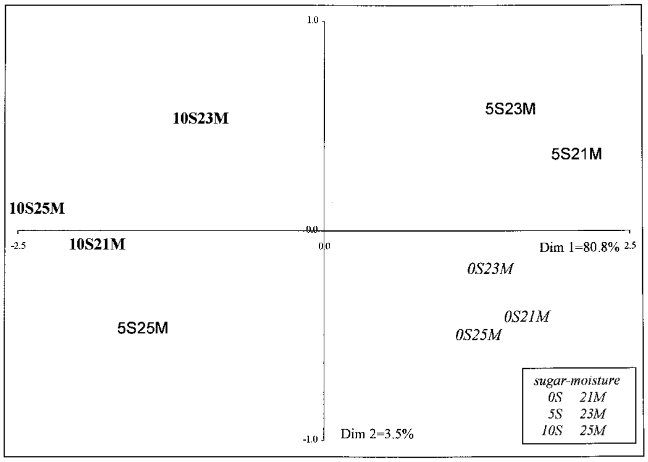

Fig. 5. Generalized procrustes analysis (GPA) sample consensus plot for sensory data combined with physical properties and extrusion processing responses of corn-soy breakfast cereals containing 0%, 5, and 10% sugar levels and processed at 21, 23, and 25% feed moisture contents. Dimension 1 accounted for 80.8% of the GPA variances, and dimension 2 accounted for 3.5%.

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