Formulation of Corn Zein Chewing Gum and Evaluation of Sensory Properties by the Time-Intensity Method

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ABSTRACT: This study was conducted to determine the feasibility of using corn zein as a natural gum base to be an alternative to the currently used synthetic gum base. The objectives were to (1) develop a corn zein chewing gum and (2) evaluate the taste, texture, and aroma qualities compared with synthetic gum base using a time-intensity (T-I) method. Four corn zein gum samples, each made with a different plasticizer (oleic acid, glycerin, propylene glycol, and 1 without any plasticizer), were included in the study along with 2 synthetic gum-base samples. Nine panelists participated in the T-I study. Thirteen attributes were evaluated. Maximum intensity, time to maximum intensity, and duration were parameters extracted from the T-I curve. The synthetic gum-base samples were rated higher for the maximum intensity of sweet taste and cinnamon aroma-by-mouth and lower for the maximum intensity of bitter taste. The propylene glycol corn zein sample was rated the highest for cinnamon aroma and the lowest for stale, rancid, and cheesy aromas. Out of the corn zein gums, the oleic acid sample was rated the lowest for the maximum intensity of hardness. It was also rated highest for the maximum intensity of bitter taste and the lowest for sweet taste. This study showed that it is feasible to use corn zein as a gum base, but future work is needed to develop an acceptable product for consumers.

Keywords: corn zein, time-intensity, chewing gum, sensory evaluation, plasticizers

Introduction

Chewing gum is a popular product worldwide. People enjoy chewing gum as a confection and in recent times as an aide to oral hygiene and an alternative to smoking.

In the United States, per capita consumption of chewing gum exceeds 195 million pounds per year (Cadbury Adams USA LLC 2004). However, chewing gum can also be perceived as an environmental pollutant, when discarded gum becomes a sticky residue adhered to surfaces in public places. Chewing gum formulations normally include gum base, softeners, sweeteners, and flavorings. Gum base, in most formulations a synthetic elastomer, is responsible for the chewy texture of gum and for its stickiness (Cook 1996). Natural, biodegradable, and less sticky alternative materials to gum base are sought after to alleviate environmental concerns.

Pliability, elasticity, and the degree of stickiness are important factors to consider when evaluating the potential for a material to be used as a chewing gum base. It is important for a chewing gum to have a high degree of pliability and elasticity and not to become firm during the mastication process. Using zein as a gum base offers nonadhesive and biodegradable properties (Cook 1996). Other components of the gum base, such as the plasticizer, promote its pliability and elasticity. Zein is a natural polymer that can be processed into an elastomeric resin, potentially useful in the manufacture of chewing gum (Cook 1996). Zein is a protein found in the endosperm of the corn kernel and functions as a major storage protein (Paulis and others 1969; Reiners and others 1973; Abe 1989). Several researchers have utilized zein in chewing gum formulations as an alternative to synthetic gum base (Weber 1939; Lougovoy 1949; Liu and others 2004). Renewed interest stems from an increased availability of zein as a byproduct of the corn ethanol industry and from the need to develop environmentally friendly, biodegradable, nonsticky gum base. Zein has also been utilized to coat other ingredients in the chewing gum. Kruppa (1984) coated sodium fluoride granules with zein to create an anticariogenetic chewing gum. Zibell (1990), Zibell and others (1992), and Campbell and Zibell (1992) applied zein as a coating for high-intensity sweeteners. Chewing gum formulations include plasticizers to soften the gum and promote chewability and mouthfeel (Hartman 1996). Plasticizers function by binding to the protein chain and creating protein-plasticizer interactions rather than protein-protein interactions (Cuq and others 1997). Effective plasticizers for zein include glycerol, propylene glycol, and oleic acid.

Sweeteners and other flavoring compounds are dispersed over the plasticized gum. The flavor intensity of chewing gum changes over time. The rate at which flavor compounds are released varies during the chewing process (de Roos 1990). The intensity generally starts out very intense and then lessens as the gum is chewed. A time-intensity (T-I) study is an effective way to monitor the changes in intensity. It describes graphically the relationship between the intensity of an attribute and how long it is perceived (Neilson 1957). A T-I study continuously monitors the intensity of an attribute over time. Multiple measurements of intensity are obtained, thus providing a detailed assessment of intensity. Thus, the objectives of this study were to (1) develop a prototype chewing gum formulation using zein as a gum base and (2) evaluate sensory properties of zein chewing gum prototypes (4 variations) in comparison with 2 synthetic gum-base samples using a T-I method.

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Table 1—Preparation steps for chewing gum samples

	Corn zein gums	Leener[a]	Discovery[a]	Copernicus
Ingredients	100 g zein[b] 5 g distilled monoglycerides 16 g partially hydro. soybean oil[c] 70 g plasticizer[d] 100 g sorbitol 10 g artificial cinnamon flavor	58 g gum base 38 g sorbitol 5 drops artificial cinnamon flavor	15 g gum base 13 g sorbitol 5 drops artificial cinnamon flavor	56 g gum base 50 g sorbitol 5 drops artificial cinnamon flavor 8 g powder sugar
Step 1	Combined above ingredients	Melted base only in microwave 3 min	Melted base only in microwave 3 min	Melted 1st 3 ingredients in microwave 40 s
Step 2	Mixed for total of 15 min	Mixed in other ingredients	Mixed in other ingredients	Stirred until blended
Step 3	Poured mixture in ice water and mixed for 1 min	Added 3 drops yellow food coloring	Added 3 drops yellow food coloring	Mixed in powder sugar and 3 drops yellow food coloring
Step 4	Kneaded and rinsed for 15 min	Kneaded 5 min	Kneaded 5 min	Kneaded 5 min
Step 5	Cut into strips	Cut into strips	Cut into strips	Cut into strips
Step 6	Rolled in flavoring (20 g sorbitol, 5 drops artificial cinnamon flavor)	Rolled in flavoring (20 g sorbitol, 5 drops artificial cinnamon flavor)	Rolled in flavoring (20 g sorbitol, 5 drops artificial cinnamon flavor)	Rolled in flavoring (20 g sorbitol, 5 drops artificial cinnamon flavor)

[a]Indicates control samples used in actual testing.
[b]Corn zein dissolved in 500 mL, 70% ethanol solution.
[c]Partially hydrogenated soybean oil added to mixture 5 min before mixing was complete.
[d]The corn zein gums were made with either oleic acid, glycerin, or propylene glycol as the plasticizer. One corn zein gum sample contained no plasticizer.

Materials and Methods

Ingredients for preparation of gum samples

Four different formulations of corn zein chewing gum samples were included in the study, which varied in the plasticizer used. One formulation had no plasticizer added. The 3 other formulations used oleic acid, glycerin, or propylene glycol. Other than the plasticizer, all of the ingredients and the amounts of each ingredient were the same for each formulation. The ingredients used in making each of the corn zein chewing gums consisted of 100 g commercial corn zein (regular grade F-4000, Freeman Industries, Tuckahoe, N.Y., U.S.A.), 500 mL of 70% ethanol (AAPER Alcohol and Chemical Co., Shelbyville, Ky., U.S.A.), 5 g distilled monoglycerides (DMG-130, ADM, Decatur, Ill., U.S.A.), 16 g partially hydrogenated soybean oil (Superb Cookie Bake, ADM), 10 g artificial cinnamon flavor (U.S. Ingredients, Inc., North Aurora, Ill., U.S.A.), 100 g of 70% sorbitol solution (ADM), and 70 g each of plasticizer, either oleic acid (Fisher Scientific, Fair Lawn, N.J., U.S.A.), propylene glycol (Fisher Scientific), or glycerin (Avatar Corp., Univ. Park, Ill., U.S.A.). One gum type had no plasticizer added. Corn zein is a food-grade protein, and all the other ingredients used in the gum formulation for this study were also food-grade quality. Table 1 shows a summary of the corn zein gum formulation.

Three control samples made with synthetic gum base were also included in this study. These gums were made from gum making kits purchased from Leener's Brew Works (Northfield, Ohio, U.S.A.), Discovery Channel Store (Florence, Ky., U.S.A.), and Copernicus (Charlottesville, Va., U.S.A.). Only the Leener and Discovery gums were used in the actual testing. The Copernicus sample was used only during the panelist training portion of the T-I study. The ingredients for preparation of the synthetic (control) gum-base samples consisted of packaged gum base in pellet form from each of the previously mentioned companies, 70% sorbitol solution (ADM) and artificial cinnamon flavor (U.S. Ingredients, Inc.). Preparation of the Copernicus sample included powdered sugar to ease the handling of the sample. The exact amounts of each ingredient for the control samples along with the preparation steps are summarized in Table 1.

Both the corn zein and control gum samples were made within 1 h before the actual sensory evaluation session.

Procedure for making corn zein chewing gum samples

All of the corn zein gums were prepared under a chemical hood to absorb the vapors released by ethanol. Aqueous ethanol solution was poured into a stainless-steel Vorwerk Thermomixer (Lake Mary, Fla., U.S.A.) followed by the corn zein and then the remaining ingredients except for the partially hydrogenated soybean oil. These ingredients were mixed together at speed 2 for 5 min. The Thermomixer has a temperature-control device that allows the temperature to be maintained at a specified level. The temperature was measured intermittently until it reached 60 °C. Mixing was continued at speed 2 for an additional 10 min at 60 °C. This mixing time and temperature thoroughly mixed all the ingredients into a homogenous mixture. The mixing action and heat promoted the evaporation of the ethanol present in the solution. To limit exposure to heat, the partially hydrogenated vegetable oil was added to the mixture 5 min before mixing was complete. The corn zein mixture was then poured into a metal container, which held 3.5 gallons of purified ice water (4.5 °C). As the mixture was being poured into the container, the water was quickly stirred for no longer than 15 s using a metal spoon. The cold water caused the zein to precipitate from the ethanol solution. The zein particles were able to aggregate together and entrap the rest of the ingredients. A dough-like resin was formed. The dough was kneaded and rinsed in 3 separate containers of purified water for 15 min to form a flexible gum base. The kneading action further blended the ingredients and rinsed away any remaining ethanol. The gum base was then spread into a thin sheet with a roller and cut into strips of 2 g each. Each strip was approximately 3 cm long, 1 cm wide, and 3 mm thick. The strips were rolled in flavoring liquid consisting of 20 g sorbitol and 5 drops artificial cinnamon flavoring. The individual strips were then placed in 30-mL plastic cups (Solo Cup Co., Urbana, Ill., U.S.A.) with lids, so they could be presented to

the panelists. The cups were coded with a 3-digit random number. All the gum samples were stored at room temperature.

The process for making the corn zein gums differed from the industrial method of gum preparation. In industrial production of chewing gum, extruders are often used for additional blending and formation of the gum (Natl. Assn. of Chewing Gum Manufacturers 2004), which was not incorporated in the preparation of the corn zein gum samples. Another difference from industrial production was the use of ice water to form the dough in corn zein gum preparation. This step was critical to the formation of the zein gums because it allowed the zein particles to aggregate together. On the other hand, the industrial method incorporates a cooling process in the production procedure, thereby allowing the gum to further set, which may last up to 48 h (Natl. Assn. of Chewing Gum Manufacturers 2004). The corn zein gums in this study were not exposed to a cooling process.

Process for making control gum samples with synthetic gum base

The synthetic gum-base samples used in the actual testing were made by melting the original gum base, in pellet form, in the microwave for 3 min. Artificial cinnamon flavoring and 70% sorbitol solution were mixed into the melted gum base. Yellow food coloring (McCormick & Co., Inc., Hunt Valley, Md., U.S.A.) was added to make the gum samples similar in appearance to the corn zein samples. The gum was kneaded for 5 min to blend all the ingredients and then rolled into a thin sheet and cut into strips of 2 g each. Compared with the corn zein gums, the control samples underwent a shorter kneading time. A longer kneading process was needed for the corn zein gum samples to minimize off-flavor from ethanol, which was used in the preparation process. The strips were rolled in flavoring liquid containing 20 g sorbitol and 5 drops artificial cinnamon flavoring. Each strip was put into a 30 mL plastic cup with a lid and labeled with a 3-digit random number. The samples were stored at room temperature.

Sensory evaluation procedure

Subjects. Nine panelists (3 M and 6 F, age 22 to 50 y), were recruited to participate in the panel. The panelists were recruited from the university community, made up of students, staff members, and local residents. None of the panelists were obtained from a previously trained group of panelists. The panelists were screened of their availability throughout the whole study. Only the users of chewing gum were asked to participate in the panel. The panelists were required to attend 1 session per day for a total of 5 wk. The total time commitment for each panelist was approximately 19 h.

Term generation. For term generation, all 6 of the gum samples included in this study were presented to the panelists with 1 to 2 samples presented each day. Descriptive terms were obtained by sniffing or chewing the gum samples. For each term, panelists had to provide a clear definition and a physical reference to represent the term. At the end of term generation, a total of 45 terms were obtained along with a physical reference. The list of terms was then reduced, so that only the terms considered significantly different across samples were included in the remaining portion of the study. Tallies were conducted among the panelists, and the list was reduced to 13 final terms, each with a physical reference. The final list of terms to describe the gum samples were cinnamon, stale, rancid, and cheesy aromas, cinnamon aroma-by-mouth, sweet taste, bitter taste, rubbery, waxy, hardness, oily mouthfeel, chewy, and cohesiveness.

Intensity rating of references. Once the terms and references were determined, panelists rated the intensity of the references in regards to all the gum samples presented. Each of the references was rated on a 10-cm line scale with anchors of (0) none and (10) extreme. The reference rating was conducted over 5 different sessions. After each session, the rating was averaged across the panelists iteratively from the previous session. The final list of terms along with the references and reference intensity values are shown in Table 2.

Table 2—Final 13 terms with description of references and reference intensity (RI) values

Modality	Reference	RI value
Aroma modality		
Cinnamon	1/2 tsp cinnamon-sugar mixture	6.5
Stale	2 small pieces stale matzo cracker	2.7
Rancid	1 tbsp rancid vegetable oil	4.3
Cheesy	1/4 piece processed American cheese slice	4.6
Aroma-by-mouth[a] modality		
Cinnamon	1/2 tsp cinnamon-sugar mixture	5.5
Taste modality		
Sweet	20 mL 3% sucrose solution	3.2
Bitter	20 mL 15% bitter (caffeine) solution	5.9
Texture modality		
Rubbery	2 pieces gummy bear candy	7.5
Hardness	1 bite size piece beef jerky	8.0
Waxy	1 candy wax bottle	7.7
Oily	1/4 piece white bread rolled in vegetable oil	4.8
Chewy	1 piece Laffy Taffy candy	6.9
Cohesiveness (L)[b]	1 tsp feta cheese	1.4
Cohesiveness (M)[c]	1 bite size piece string cheese	3.9
Cohesiveness (H)[d]	1 bite size piece lowfat cheddar cheese	6.2

[a]Aroma-by-mouth = retronasal aroma perceived when the sample is in the mouth.
[b]L = Low.
[c]M = Medium.
[d]H = High.

Panel training for intensity rating of line scale attributes. For the line scale attributes (cinnamon aroma, cheesy aroma, stale aroma, rancid aroma, waxy, cohesiveness), panelists were trained to sniff the gum sample using short bunny sniffs and then mark the aroma intensity on a 10-cm line scale with anchors of (0) none and (10) extreme. The corresponding reference intensity values were marked on each of these scales.

Panel training for T-I attributes. Initially for the T-I training, panelists used paper ballots containing 10-cm line scales corresponding to a specified time (0 s, 5 s, 10 s, 20 s, . . . 90 s). The panel facilitator held a stopwatch and when the specified time was reached, the facilitator would instruct the panelists to mark the perceived intensity on the corresponding scale. Each of these scales had anchors of (0) none and (10) extreme along with the reference intensity value. This procedure was done for each of the T-I attributes (cinnamon aroma-by-mouth, sweet taste, bitter taste, rubbery, hardness, oily mouthfeel, chewy). Toward the end of training, panelists were instructed on how to rate the intensity of these attributes using a computerized T-I program (Compusense *five* 4.2, Compusense, Inc., Guelph, Ont., Canada).

Actual testing. Four corn zein and 2 synthetic gum-base samples were evaluated in the actual testing phase. Two replications were included with 1 type of gum evaluated per day. Compusense *five* 4.2 (Compusense, Inc.) computer software was used for rating both the line and T-I attributes. The order of appearance of attributes during testing consisted of first rating the line scale attributes (cinnamon aroma, cheesy aroma, stale aroma, rancid aroma, waxy, cohesiveness) and then the T-I attributes (cinnamon aroma-by-mouth, sweet taste, bitter taste, rubbery, hardness, oily mouthfeel, chewy). Panelists reviewed each of the references and the reference intensity values before each of the actual testing sessions.

The line scale attributes were evaluated with a single intensity rating on 10-cm line scales. The T-I attributes were evaluated con-

Table 3—Analysis of variance of 6 sensory attributes and 21 time-intensity parameters rated for gum samples[a]

Parameters extracted from T-I curve	Judge	Replication	Sample	R × J	R × S	S × J
Sweet time to max	1.74	2.18	1.09	2.07	1.67	1.25
Bitter time to max	12.97***	1.81	0.1	0.78	0.71	1.82*
Rubbery time to max	7.13***	0.24	2.02	1.07	0.14	1.24
Oily mouthfeel time to max	12.60***	1.51	2.26	0.3	0.57	1.07
Hardness time to max	8.04***	0.04	2.53*	0.2	0.82	0.7
Cinnamon time to max	2.65*	0.25	0.95	1.02	0.71	0.63
Chewy time to max	10.61***	2.76	0.66	1.91	0.05	1.28
Sweet duration	11.14***	3.5	0.97	1.97	0.7	1.67
Bitter duration	8.96***	20.22***	17.15***	1.73	1.99	2.17**
Rubbery duration	7.71***	0.03	0.4	0.16	0.76	1.31
Oily duration	11.33***	0.03	6.17***	2.97*	1.91	1.48
Hardness duration	6.73***	5.07*	0.62	6.40***	0.97	0.91
Cinnamon duration	22.02***	2.92	2.81*	1.53	0.55	2*
Chewy duration	13.06***	8.25**	1.95	4.31***	1.64	1.57
Sweet max intensity	3.87**	3.43	36.53***	1.13	0.7	1.33
Bitter max intensity	4.29***	8.72**	31.11***	1.37	1.74	2.26**
Rubbery max intensity	27.61***	0.86	1.02	1.4	2.15	0.69
Oily max intensity	6.29***	0.06	1.68	0.7	0.8	0.7
Hardness max intensity	18.19***	0.12	8.27***	2.62*	0.83	0.66
Cinnamon max intensity	2.63*	0.68	14.70***	1.25	0.48	1.59
Chewy max intensity	25.98***	1.67	3.04*	4.07**	1.59	1.82*
Attributes on a line scale						
Cohesiveness line scale	14.56***	1.59	7.62***	1.25	1.72	1.23
Waxy line scale	13.65*	5.59*	1.39	0.77	3.27*	0.86
Stale aroma line scale	18.86***	0.79	6.90***	1.05	3.18*	1.18
Rancid aroma line scale	9.35***	2.16	7.75***	1.36	1.43	1.17
Cheesy aroma line scale	20.74***	5.27*	9.44***	1.06	2.44	1.38
Cinnamon aroma line scale	6.48***	8.40**	6.09***	1.5	2.32	1.03

[a]F-values are shown for the sources of variation. J = Judge; R =Replication; S = Sample; T-I = time-intensity.
*, **, *** indicate significance at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively.

Table 4—Adjusted F-values using analysis of variance (ANOVA) on the gum treatments with significant Judge × Sample interaction as the error term

Modality	Parameters extracted from T-I curve	Adjusted F-value
Taste	Bitter duration	7.90***
	Bitter max intensity	13.77***
Aroma-by-mouth	Cinnamon- duration	1.41
Texture/Mouthfeel	Chewy max intensity	1.67

*, **, *** indicate significance at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively. T-I = time-intensity.

tinuously for 90 s using a T-I scale. With the computerized T-I program, panelists clicked on the slider and moved up or down the scale according to the intensity. If the intensity stayed constant, the panelists held the slider in place where the intensity started to stay constant. A timer was displayed on the computer screen to inform the panelists of the remaining time. When panelists evaluated bitter, sweet, cinnamon aroma-by-mouth, and oily mouthfeel, they expectorated the samples at 60 s and rated the lingering intensity of these attributes until 90 s. A signal flashed above the scale to remind the panelists to spit out the gum at this time.

It is realized that 90 s is atypical of chewing gum testing and that a longer time of 5 to 20 min would be more appropriate for evaluation. This study was conducted to determine the feasibility of using corn zein in chewing gum. Restricting the evaluation time to 90 s allowed each of the panelists to evaluate all 7 of the T-I attributes in each session. Once the corn zein gum is further developed, a longer evaluation time would be appropriate.

Both the line and T-I scales were marked with the corresponding reference intensity value and had anchors of (0) none and (10) extreme. For each test session, each panelist was given a total of 8 pieces of gum, one at a time. One piece of gum was used to rate the 6 line intensity attributes and the others were used to evaluate each of the 7 time-related attributes. Testing was done in an individual booth setting in the sensory evaluation laboratory. Red lighting was used to mask any color differences. Panelists were instructed to rinse their mouth before beginning each session and after chewing each piece of gum. The rinsing protocol consisted of eating a piece of matzo cracker (Manischewitz Co, Jersey City, N.J., U.S.A.), swallowing warm water, and then swallowing room-temperature water. This rinse protocol was also followed in the training portion of the study. Once a panelist finished evaluating an attribute, the next piece of gum was provided immediately.

Statistical analysis

Maximum intensity, time to maximum intensity, and duration were the parameters extracted from the T-I curves generated. Results were analyzed using analysis of variance (ANOVA) with least significant difference (LSD) multiple comparisons by Statistical Analysis Systems (SAS) program version 8.2 (Cary, N.C., U.S.A.).

Principal component analysis (PCA) using a correlation matrix was conducted on attributes showing a significant difference among the gum samples by ANOVA.

Results and Discussion

As shown in Table 3, judges were shown to be a major source of variation, as indicated by the significant F-value of judges. This is a typical outcome of descriptive analysis, indicating that judges are using different parts of the scale. The data showed good reproducibility shown by the F-value of the sensory replication not being significant in majority of the attributes/TI parameters.

The ANOVA table showed 7 parameters or attributes as signifi-

Table 5—Treatment means and least significant differences (LSDs) for attributes with a significant difference for sample[a]

Parameters extracted from T-I curve	Corn zein No plasticizer	Corn zein Glycerin	Corn zein Propylene glycol	Corn zein Oleic acid	Control Discovery	Control Leener
Hardness time to max[b]	46.39a	39.56a	34.61ab	49.67a	17.28b	40.17a
Bitter duration[b]	79.81a	80.94a	66.97b	89.56a	67.64b	41.47c
Oily duration[b]	79.78ab	76.69abc	75.22bc	88.11a	67.36cd	59.56d
Sweet max intensity[c]	17.50c	16.94c	19.61c	13.89c	43.22b	53.11a
Bitter max intensity[c]	24.94b	19.39bc	20.89b	57.11a	11.22cd	8.11d
Hardness max intensity[c]	38.50b	38.39b	40.56b	24.50c	52.61a	50.89a
Cinnamon max intensity[c]	19.00b	15.56b	18.94b	16.00b	34.06a	40.06a
Attributes on line scale[d]						
Cohesiveness line scale[d]	4.51c	4.41c	6.77a	6.04a	4.89bc	5.87ab
Stale aroma line scale[d]	1.98a	1.37bc	0.65d	0.83cd	1.68ab	0.82cd
Rancid aroma line scale[d]	2.51a	1.83ab	0.42d	0.96cd	2.29a	1.42bc
Cheesy aroma line scale[d]	2.52a	2.41a	0.89c	1.56b	2.47a	1.71b
Cinnamon aroma line scale[d]	3.56bc	3.27bc	5.08a	4.31ab	2.76c	4.86a

[a]Means with different letters in a row are significantly different. T-I = time-intensity.
[b]Time parameters measured in seconds.
[c]Intensity parameters measured as a percent with a maximum of 100.
[d]Scale range from 0 to 10 cm.

cantly different for replication. For the majority of the parameters and attributes, the panel was reproducible over replications.

The data showed good reproducibility between the judges in the 2 sensory replications. Among the 21 parameters extracted from the curve and the 6 attributes rated on a line scale, only 5 of these parameters and attributes were noted with a significant difference for replication by judge interaction. The 5 attributes that had significant replication by judge interaction showed that judges were not agreeing across the 2 replications of which 1 is higher or lower in intensity. However, 3 of the 5 did not show a significant difference in replications, indicating that the judges, for the most part, were rating the samples consistently in the 2 sensory replications.

Among the samples, 14 parameters or attributes were found to be significantly different. The attributes or parameters found to be significantly different were evenly distributed among the time- and intensity-related parameters as well as the line scale attributes.

Significant differences were noted for the sample × judge interaction in some attributes. Out of the 14 significant parameters or attributes, 4 were found with a significant difference in sample by judge interaction, indicating panel inconsistency for these attributes. A mixed-model ANOVA with an adjusted F-test was conducted on these 4 attributes (Table 4) using the sample × judge interaction as the error term. Two of the 4 terms remained significantly different after conducting the adjusted F-test. These terms included bitter duration and maximum intensity of bitter.

The LSD multiple comparisons table (Table 5) was created for the final list of 12 parameters or attributes with a significant difference across the samples.

Compared with the corn zein samples, the control samples received lower mean scores for the maximum intensity of bitterness and the 2 highest scores for the maximum intensity of sweet taste and cinnamon aroma-by-mouth. One possibility for the lower scores for sweetness and cinnamon aroma-by-mouth for the corn zein samples was that the corn zein could have suppressed the sorbitol and cinnamon flavorings and that increased amounts of these flavorings would have to be added for them to be more comparable to the synthetic gum samples. Regarding the lower bitterness scores for the control samples, it has been documented that different tastes can suppress one another (Lawless and Heymann 1999). Therefore, the high sweetness of the control samples could have suppressed the bitter taste.

Sorbitol and cinnamon flavoring were the main ingredients contributing to sweetness and cinnamon aroma-by-mouth attributes. All the gum samples tested contained an approximate 1:1 ratio of base to sorbitol except for the Leener control sample, which had a ratio for base to sorbitol of 1.5:1. For each control gum sample, ingredients and instructions followed were provided by the manufacturer, which resulted in the different amount of sorbitol added. Although the Leener control sample had the smallest sorbitol to base ratio, it received the highest mean score for the maximum intensity of sweet taste. This finding may be attributed to an uneven distribution of sorbitol in the Leener sample. The uneven distribution may have created pockets of sorbitol, thus contributing to greater sweetness. The flavor coating added to each piece of gum after preparation was the same for the corn zein and synthetic gum base samples.

Of all the samples, the propylene glycol plasticized zein sample received the lowest mean scores for stale, rancid, and cheesy aromas and the highest mean score for cinnamon aroma. This is a positive finding for the propylene glycol sample since stale, rancid, and cheesy aromas are regarded as off-flavors and cinnamon is a more desirable attribute.

The propylene glycol sample also had a slightly higher mean score for the maximum intensity of sweet taste among the corn zein samples. This finding can be attributed to the hydrophilicity of the plasticizer. Propylene glycol was the most hydrophilic plasticizer used in the corn zein gums. It is therefore speculated that the more hydrophilic plasticizer had better binding ability for sorbitol thus helping to retain it in the gum mixture.

Of the corn zein gums, the oleic acid sample appeared to have the most desirable texture with the lowest mean score for the maximum intensity of hardness. Different from the glycerin and propylene glycol samples, oleic acid is largely hydrophobic. This explained why it functioned most effectively as a plasticizer compared with the other plasticizers. Since zein is also hydrophobic, the oleic acid was better able to bind to the protein and induce flexibility.

The oleic acid sample had the longest duration for oily texture. Due to the fact that oleic acid is derived from vegetable oils (Mensink and others 2002), it was not unexpected for this sample to be rated highest for oiliness.

For taste, the oleic acid sample had the highest mean score for the duration and maximum intensity of bitterness and the lowest mean score for sweet taste. Although the oleic acid in this study was not rancid, oleic acid has a natural tendency to become rancid and produce off-flavors. According to Stauffer (1996), bitterness is one indicator of rancidity. The taste of oleic acid before oxidation is not

Table 6—Correlation matrix of the mean sensory ratings across 6 gum samples

Attributes	Hardtime	Bittdur	Oilydur	Sweetmax	Bittmax	Hardmax	Cinmax	Cohline	Stalline	Ranline	Cheeline	Cinline
Hardtime	1.00											
Bittdur	0.34	1.00										
Oilydur	0.56	0.94**	1.00									
Sweetmax	–0.53	–0.88*	–0.93**	1.00								
Bittmax	0.62	0.74	0.89*	–0.69	1.00							
Hardmax	–0.75	–0.80	–0.94**	0.85*	–0.94**	–1.00						
Cinmax	–0.51	–0.87*	–0.91*	0.99***	–0.65	0.84*	1.00					
Cohline	0.10	–0.29	–0.01	0.05	0.23	–0.15	0.07	1.00				
Stalline	–0.21	0.30	0.05	–0.06	–0.22	0.21	–0.03	–0.89*	1.00			
Ranline	–0.23	0.09	–0.17	0.20	–0.34	0.36	0.21	–0.92**	0.95**	1.00		
Cheeline	–0.18	0.21	–0.07	0.09	–0.24	0.24	0.09	–0.98***	0.91*	0.97**	1.00	
Cinline	0.43	–0.40	–0.06	0.02	0.15	–0.18	0.03	0.87*	–0.84*	–0.83*	–0.90*	1.00

*, **, *** indicate significance at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively.
Bittdur = bitter duration; Bittmax = bitter maximum intensity; Cheeline = cheesy aroma line scale; Cinline = cinnamon aroma line scale; Cinmax = cinnamon aroma-by-mouth maximum intensity; Cohline = cohesiveness line scale; Hardmax = hardness maximum intensity; Hardtime = hardness time to maximum; Oilydur = oily duration; Ranline = rancid aroma line scale; Stalline = stale aroma line scale; Sweetmax = sweet maximum intensity.

discussed in literature, but possibly it resembles bitter. The low sweetness score for the oleic acid sample is attributed to the high bitterness of the oleic acid suppressing the sweet taste. This can be expanded to all the corn zein gums. They were all rated higher for the maximum intensity of bitterness and lower for sweet taste compared with the control samples.

Table 6 illustrates a correlation matrix of the mean sensory ratings across the samples. The highest correlation ($r = 0.99$, $P < 0.001$) was noted between the maximum intensity of cinnamon aroma-by-mouth and the maximum intensity of sweet taste. This indicated that the maximum intensity of cinnamon aroma-by-mouth changed in the same direction and proportion as the maximum intensity of sweet taste.

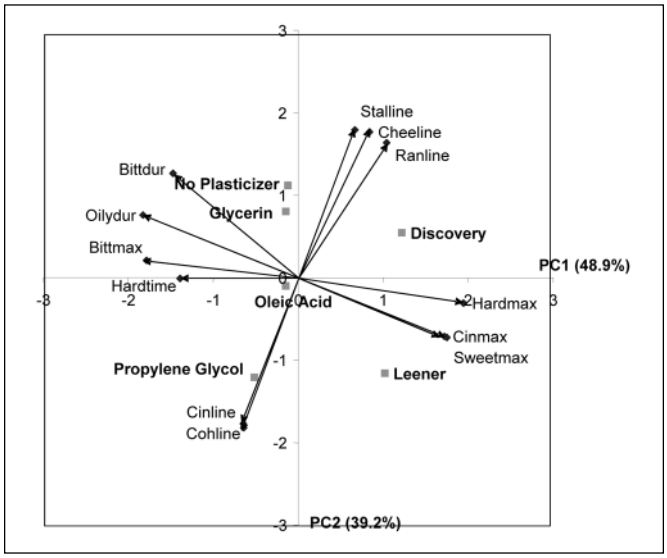

Figure 1—Principal component analysis (PCA) biplot of the correlation matrix of mean sensory attribute ratings and time-intensity (T-I) parameters across the samples. The attributes and parameters are shown as vectors, and the gum samples are indicated with squares. Bittdur = bitter duration; Bittmax = bitter maximum intensity; Cheeline = cheesy aroma line scale; Cinline = cinnamon aroma line scale; Cinmax = cinnamon aroma-by-mouth maximum intensity; Cohline = cohesiveness line scale; Hardmax = hardness maximum intensity; Hardtime = hardness time to maximum; Oilydur = oily duration; Ranline = rancid aroma line scale; Stalline = stale aroma line scale; Sweetmax = sweet maximum intensity.

Other positive correlations were also found between cheese and rancid aromas, between rancid and stale aromas, between cheese and stale aromas, and between oily duration and the duration of bitter taste.

The highest negative correlation was found between cheese aroma and cohesiveness ($r = –0.98$, $P < 0.001$). Other negatively correlated relationships were found between rancid aroma and cohesiveness, between cinnamon and cheesy aromas, between maximum intensity of hardness and maximum intensity of bitter taste, between maximum intensity of sweet taste and oily mouthfeel duration, between maximum intensity of hardness and oily mouthfeel duration, and between maximum intensity of cinnamon aroma-by-mouth and oily mouthfeel duration.

Figure 1 represents a PCA plot of the correlation matrix of mean sensory attribute ratings and T-I parameters across the samples. This figure showed PC1 explaining 48.9% of the variance and PC2 with 39.2% of the variance. Together they illustrated 88.1% of the total variation. PC1 contained the intensity-related parameters and the time-related parameters, hardness time to maximum and oily mouthfeel duration. Bitter duration was not explained well by this plot. PC2 contained the line scale attributes. The plot showed the propylene glycol sample to be the least associated with stale, rancid, and cheesy aromas. The Leener and Discovery samples were closely related to maximum intensities of hard, sweet, and cinnamon aroma-by-mouth. The oleic acid sample was not explained well by this plot. The no plasticizer and glycerin samples were characterized primarily by the bitter and oily duration, maximum intensity of bitter, and hardness time to maximum.

Conclusions

This study demonstrated the feasibility of using corn zein as a gum base and its potential for future optimization. Two corn zein samples included in this study showed potential for future optimization. The formulation containing propylene glycol received the lowest mean intensities for off-flavors, that is, stale, rancid, and cheesy, and the highest for cinnamon aroma. The formulation containing oleic acid had the lowest mean score for the maximum intensity of hardness, demonstrating its desirable textural characteristics.

A possible way to further improve on sensory properties of zein gums is to incorporate waxes in the formulation, which can improve flavor release, shelf life, and texture. By examining the results of this study, advances can be made in the application of corn zein to chewing gum and possibly to other food products. Much work still needs to be done to create an acceptable corn zein chewing gum for consumers.

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