THE UNIVERSITY OF MANITOBA

SWEETNESS PERCEPTION IN FIVE HYDROCOLLOID GELS VARYING IN INSTRUMENTALLY ASSESSED TEXTURAL CHARACTERISTICS

by

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ABSTRACT

Sensory examination of 5 hydrocolloid gels prepared to be similar in hardness and containing equal proportions of sodium Sucaryl showed gelatin and cornstarch gels to be significantly less sweet ($P < 0.01$) than gels of agar, low methoxyl pectin (LMP) and carrageenan, with carrageenan gels being the sweetest ($P < 0.01$). A 7-member panel, trained to discriminate sodium Sucaryl differences of 0.027% with at least 65% accuracy, consistently placed the hydrocolloids in the same sweetness order in 4 replications of a multiple paired comparison experiment. Objective textural characterization of these gels with a General Foods Brabender Texturometer revealed no evidence of brittleness or adhesiveness. Despite efforts to match gels in hardness, and rigorous control of experimental conditions, differences in this parameter were significant at the 5% level of probability. Hardness differences of the same magnitude prepared by varying gelatin concentrations were detectable by mouth to a 47-member untrained panel ($P < 0.01$). Instrumental data also showed significant differences ($P < 0.01$) among gels in cohesiveness, springiness, chewiness and gumminess with gelatin and cornstarch having the larger values in all these parameters. Analysis of covariance applied to sensory and instrumental measurements on the

same gel lots showed sweetness differences to be significant despite adjustment for measured textural differences. Multiple correlation analysis applied to the same results indicated that together, all 5 textural parameters accounted for 52.32% of the variability in sweetness. Inspection of correlation coefficients for single textural parameters showed no one characteristic as a dominating influence over sweetness.

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INTRODUCTION

The use of hydrocolloids or "gums" in processed food products is increasing due to their versatility as stabilizers in beer or mayonnaise, thickeners in jams, sauces and pie fillings, gelling agents in dessert products and coating agents in various confections. With this increased use has come a renewed interest in their chemical and physical properties and the effect these have on the other constituents of the food product in which they are used.

Different hydrocolloids are known to form gels differing in texture, however, these differences are not well described instrumentally. Since hydrocolloids added to foods may affect both their texture and flavor, two characteristics which influence consumer acceptance noticeably, textural description is necessary in the selection of hydrocolloids for various uses.

As well as modifying the textural characteristics of products, there is evidence in the literature to suggest that some hydrocolloids mask taste perception. For example, low concentrations of carboxymethylcellulose (CMC) have been shown to decrease perception of sweetness (Stone and Oliver, 1966) and saltiness (Moskowitz and Arabie, 1970). There is further evidence to suggest that this masking varies with

the type of hydrocolloid used (Vaisey et al., 1969).

Although these masking effects have been reported mainly in sols of hydrocolloids, it is possible that they may also be manifest in hydrocolloid gels since gels are semi-rigid, elastic substances formed from colloidal sols. To the present, however, very little has been reported on the nature of taste-masking in gels.

The purpose of this study, therefore, was to assess the effect of five different hydrocolloids on the perception of sweetness in gels and to determine whether taste-masking effects could be predicted by objective measurements on the gels.

REVIEW OF LITERATURE

Taste and Sweetness Perception

An appreciation of the mechanics of taste and sweetness perception is necessary before one can study the effects of texture on taste perception.

Often described in terms of one or more of the four basic modalities of salt, sweet, bitter or sour, taste is the sensation produced when food is taken into the mouth and stimulates the taste receptors of the tongue (Beidler, 1966). The areas of the tongue giving a preferential response to the four modalities have been established, as shown in Figure 1, on the basis of electrophysiological studies. However, the actual mechanics of taste perception are still not clearly established (Anon., 1967; Dastoli, 1968; Amerine et al., 1965). Although not conclusively proven, it is a widely accepted fact by most workers in the field of taste perception that taste is perceived as the result of the reaction of taste molecules with a chemoreceptor in the tongue (Dastoli and Price, 1966; Amerine et al., 1965).

As far as perception of sweetness is concerned, a number of theories have been advanced. These include theories correlating chemical structure or physical properties of various compounds with degree of sweetness perceived, and those suggesting that taste is the result of enzyme

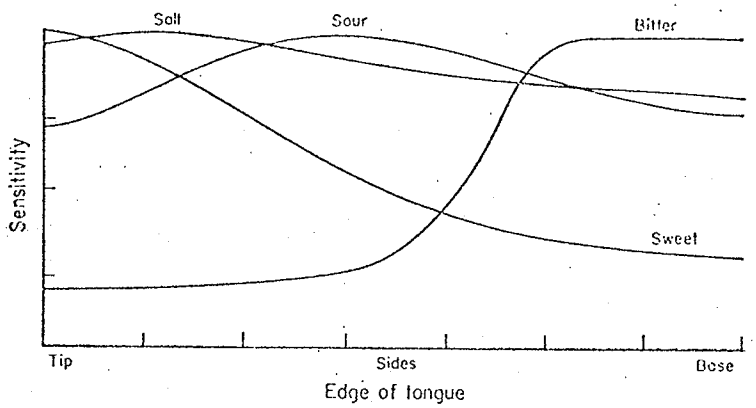


Figure 1. Sensitivity of areas of taste on the tongue (Amerine et al., 1965)

reactions (Amerine et al., 1965; Dastoli and Price, 1966; Dastoli, 1968).

Because compounds eliciting a sweet taste differ widely in shape and size, it would seem that theories based simply on chemical structure and not considering stereo-chemical structure, are of limited use. Similarly, since responses to taste stimuli are independent of pH (3-11) and temperature (20^{o}-30^{o}C) (Dastoli, 1968) and because addition of various enzyme inhibitors does not appear to obliterate sweetness irreversibly (Lawrence and Ferguson, 1959), it is unlikely that enzyme theories can adequately explain sweetness perception (Dastoli and Price, 1966).

At this time, the theory that sweetness perception results from the formation of a weak complex, due to hydrogen bonding, between the "sweet" molecule and a protein in the taste receptor, seems to be the most promising.

Shallenberger and Acree (1967) have suggested the existence of a molecular feature of stereo-chemical nature, and common to all molecules which elicit a sweet taste. In this system, known as an AH, B system, A and B are electronegative atoms such as oxygen, nitrogen and sometimes chlorine or carbon. The critical distance between these atoms is greater than 2.5Å and less than 4Å. The H represents a hydrogen atom, covalently bonded to A with the result that AH is a proton donor and B is a proton acceptor.

Theoretically sweetness is perceived when this bifunctional system interacts with a taste-bud based receptor site thought to be another bifunctional unit similar in nature to the AH, B system of the sweet molecule. Conceivably this interaction involves the simultaneous formation of two hydrogen bonds as shown in Figure 2. The structural nature of this system is such that it accounts for the sweetness of artificial sweeteners like saccharine and cyclamates as well as that of natural sweeteners.

When Shallenberger and Acree (1967) proposed the existence of this AH, B system they suggested that the receptor site was probably a protein peptide bond or protein amide group of glutamine or asparagine. In 1966, Dastoli and Price, working with extracts of bovine taste buds, succeeded in isolating a "sweet-sensitive" protein with a molecular weight of 150,000 $\pm$ 3,000. It contained less than 10% carbohydrate, was highly alkaline and high in lysine and proline (Dastoli and Price, 1968). This protein forms complexes with sugars and other sweetening agents, such as cyclamates, in direct relationship to their concentration in solution. Interaction energies involved in the formation of these complexes were calculated and found to be between 1 to 4 Kcal/mole. These values suggest the occurrence of weak physical interactions similar in strength to those exhibited during hydrogen bonding (1 to 2 Kcal/mole), rather than covalent interactions (Dastoli, 1968; Dastoli and Price,

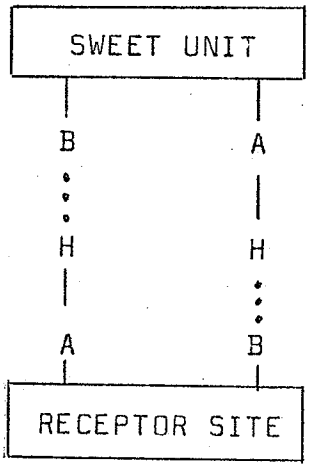


Figure 2. Proposed H bonding between sweet compound and receptor site thought to be responsible for sweetness perception (Shallenberger and Acree, 1967)

1966). Dastoli (1968) reported that not only did this protein discriminate among sugars but that the selectivity was in the correct order of their sweetness as reported in studies with human tasters. Furthermore, this protein contains a large amount of lysine which has the proper configuration to act as an AH, B bifunctional unit with the amine group being AH and the carbonyl of the peptide bond as B (Dastoli, 1968).

In conclusion, the discovery and isolation of this "sweet-sensitive" protein and the fact that the AH, B system is a unit common to all sweet tasting compounds regardless of chemical class make Shallenberger's theory of sweetness perception the most credible one to this time.

Texture Perception

In addition to an understanding of the mechanism of sweetness perception, it is also necessary to have some comprehension of texture in order to be able to study taste-texture interactions which may occur in foods.

Because the texture of a food is often perceived before its taste, the study and assessment of texture is important for prediction of consumer acceptance at time of purchase and preparation as well as during consumption (Szczesniak, 1963, 1966b, 1968, 1969). In addition, it has been reported to influence food habits, to affect processing and handling of food products and to affect oral health

(Szczesniak, 1966b, 1969). In 1963, Szczesniak and Kleyn reported that the consumer has a high awareness of texture in various foodstuffs and that for some foods, such as celery and pie crust which are bland in flavor, or those, such as peanut butter, which are highly representative of a specific texture, texture is more important than flavor (Szczesniak, 1969; White, 1970). Rasekh et al. (1970), however, reported that consumer preference for canned tuna appeared to be only 20% texture dependent while it was 40% dependent on both appearance and flavor.

Despite the large amount of research reported to date on texture of foods, it seems that no one has been able to produce a concise, objective definition of "texture." Kramer (1959) and Amerine et al. (1965) define texture as those properties of a foodstuff, apprehended by the eyes and by the skin and muscle senses in the mouth, including the roughness, smoothness, graininess etc, while Szczesniak (1963) considers it to be "the composite of the structural elements of the food and the manner in which it registers with physiological senses." In other words, texture encompasses not only the deformation and flow, i.e. the rheological properties of a foodstuff, but also their physiological and psychological perception. Corey (1970) suggests that the occurrence of difficulties in producing a concrete definition of texture may be due to a problem in semantics. Each person has his own concept of what texture is; it is

only when one wishes to define the terms or sensations associated with it that difficulties arise since each interprets the descriptive terms in relation to his own experiences.

In an attempt to reduce this problem of semantics, Szczesniak (1963) studied the many terms used by various researchers in the study of texture and established a system for classification of textural characteristics as shown in Figure 3. This system of classification reduces the number of adjectives applied to the texture of foods and can be accommodated to both objective and sensory methods of texture evaluation. It also serves as the basis of Szczesniak's (1963) rating scales for mechanical parameters of texture used in sensory texture description.

Another way in which semantic difficulties can be overcome during textural study of foods is by the use of mechanical texture measuring machines to quantify objectively various textural characteristics of the foods under consideration. By doing this, each food can be assigned a numerical value for each characteristic and subsequently be compared to each other mathematically. Corey (1970) points out that, at some point, the machine must be calibrated against related sensory evaluations. He appends this, however, by saying that, given constant test conditions, the machine will measure all samples the same way every day, an occurrence not possible with a sensory panel since it is not

A. MECHANICAL CHARACTERISTICS

Primary parameters	Secondary parameters
Hardness	Brittleness
Cohesiveness	Chewiness
Adhesiveness	Gumminess
Elasticity	
Viscosity	

B. GEOMETRICAL CHARACTERISTICS

Class

Particle size and shape
Particle shape and orientation

C. OTHER CHARACTERISTICS

Primary parameters	Secondary parameters
Moisture content	Oiliness
Fat content	Greasiness

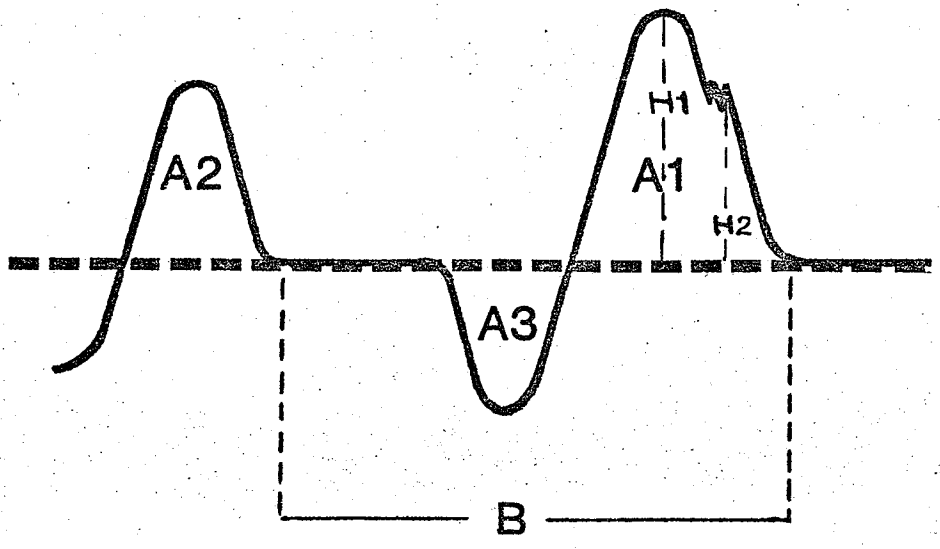
Figure 3. Classification of Textural Characteristics (Szczesniak, 1963)

possible to eliminate completely bias, fatigue, learned responses, mental set and other confounding variables in human panelists.

Since texture has been shown to be a complex of numerous parameters simultaneously perceived, analyzed and integrated by the human mouth, it is likely that machines measuring a number of parameters at one time would give a better correlation with sensory measurements than would those that make single parameter measurements (Szczesniak, 1968). It is to this end that the General Foods Brabender Texturometer was developed (Szczesniak, 1966b).

This machine, described in detail by Friedman et al. (1963) and Szczesniak (1966a), was designed to measure the primary parameters of hardness, cohesiveness, elasticity and adhesiveness, simultaneously. The secondary parameters of brittleness, chewiness and gumminess, composed of two or more primary parameters, can then be derived mathematically from the results obtained from the primary values. Figure 4 illustrates a classical Texturometer curve and formulae used to calculate the results for the primary and secondary parameters.

Szczesniak (1963) reported that Texturometer values appeared to be well correlated with sensory evaluations made by a 9-member trained texture-profile panel. This is likely due to the fact that these observations were based on results, published by Szczesniak and co-workers (1963), of



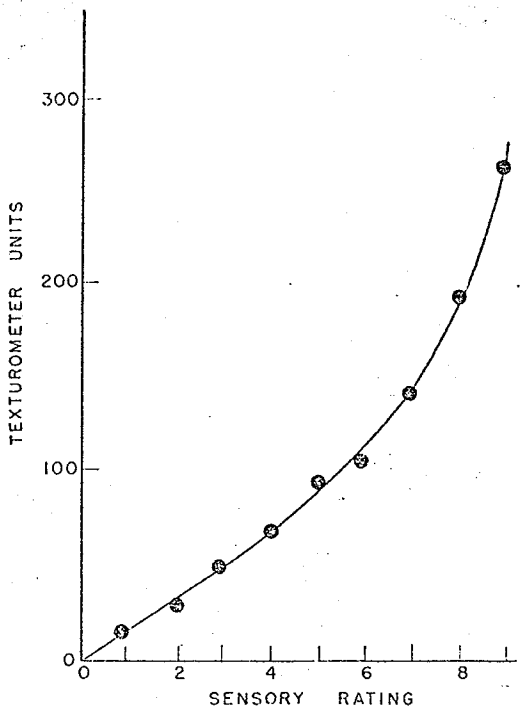
Formulae for textural parameter calculations

1. Hardness = H_1/volts input
2. Cohesiveness = A_2/A_1
3. Adhesiveness = A_3
4. Brittleness = H_2/volts input
5. Gumminess = Hardness x Cohesiveness
6. Chewiness = Hardness x Cohesiveness x Elasticity
7. Elasticity or Springiness = C-B where C = Time constant for clay

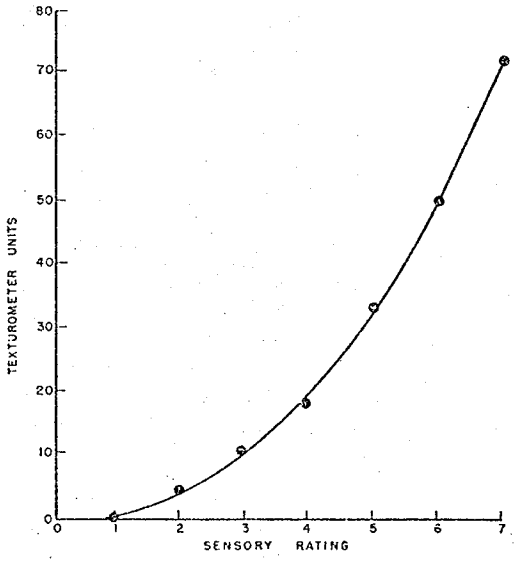
Figure 4. A Classical Texturometer Curve and Formulae for Calculation of Textural Parameters (Friedman et al., 1963)

objective and sensory evaluations on their developed standard scales for hardness, brittleness, chewiness, gumminess and adhesiveness. Foods used in these standard scales were chosen because they were highly representative of the specific scale points, thus good correlations would be expected. Correlation was curvilinear for objective and sensory results of parameters hardness and brittleness, when rectangular graph paper was used (Figures 5a and b). Chewiness and adhesiveness showed linear relationships when plotted on rectangular graph paper, and gumminess showed the same relationship when plotted on semi-log paper (Figures 5c, d and e). According to the authors, these correlations indicate that the Texturometer was able to measure the same intensity of textural parameters as discerned by the sensory panelists. Work done on evaluation of samples of beef and pork, fresh and freeze-dried (Szczesniak et al., 1970) using both the Texturometer and a texture-profile panel showed significant correlations ($P < 0.01$) for hardness and chewiness.

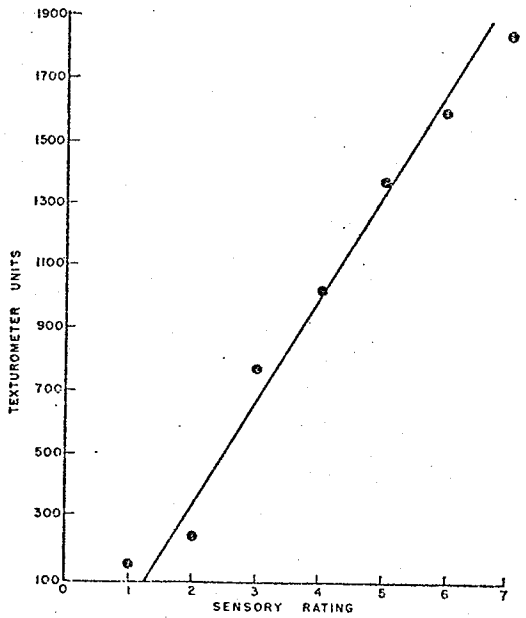
Brennan et al. (1970) also reported that correlations between Texturometer readings and evaluations by a 13-member trained sensory panel, indicated a fairly good agreement among Texturometer hardness values and panel scores for firmness/hardness of various foods tested. Cohesiveness was also shown to correlate with panel firmness. Foods tested were different varieties of apples, types of cheese, toffee



a. Hardness

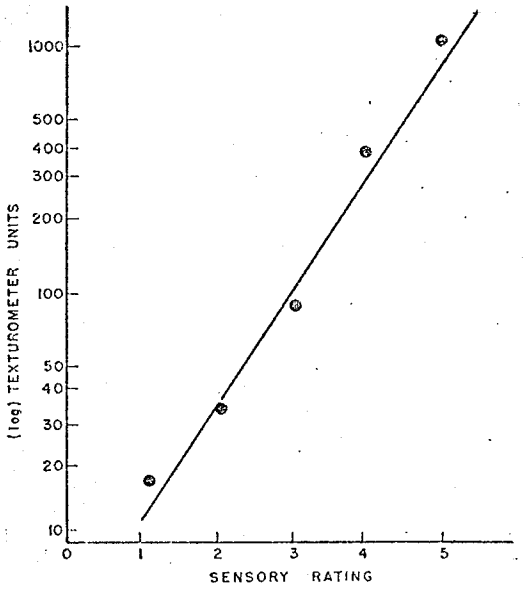


b. Brittleness

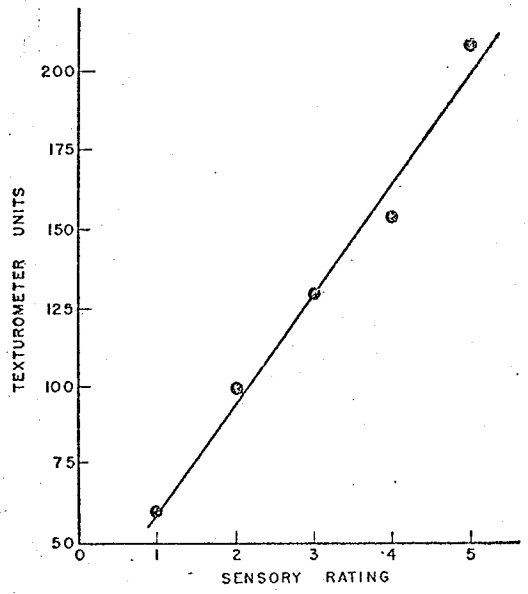


c. Chewiness

Figure 5. Relation Between Sensory Rating and Texturometer Readings for Hardness, Brittleness, Chewiness, Adhesiveness and Gumminess (Szczesniak et al., 1963)



d. Adhesiveness



e. Gumminess

and cake.

In summary, "texture" is difficult to define, as it is a complex of rheological properties, each of which must be measured. Because this is so, evaluation methods reducing as many variables as possible are preferential. Instrumental methods tend to reduce this variability and give more repeatable results than human judges. Since texture is so complex, however, and can only truly be evaluated by the human mouth, an instrument such as the Texturometer, which gives repeated "chews" on a sample, measures more than one textural characteristic at a time and shows good correlation of results with those from sensory panels, is to be preferred for use in objective texture assessment of foods.

Taste-texture Interaction

Up to this point, taste and texture have been treated as two independent variables. Since, however, they are both present in any one foodstuff, are both perceived by various means in the mouth, it may be possible that some interaction between these two properties occurs which renders them no longer independent. Börnstein (1940) reported that the gustatory and somatosensory systems have a close anatomical and neural relationship, and suggested that there is evidence that gustation, that is taste, may be a derived tactile sense which would account to some degree for the presence of taste-texture interactions.

The literature contains very few reports of experiments conducted to investigate taste-texture interactions.

According to Stone and Pangborn (1968), one of the earliest studies on taste-texture interaction was reported in 1926 by von Skramlik. He found that taste intensity was greater in an aqueous medium than in paraffin oil. From these findings, Stone and Pangborn (1968) speculated that the physical state of an oral stimulus could influence taste perception by partially controlling the amount of taste material reaching the taste receptors in a given time. This theory was also proposed in 1945, by Crocker, who reported that thin, strong tasting liquids seem to have weaker flavors if thickened with algin, gum tragacanth or other mucilagenous matter. He suggested that this might be caused by the viscosity of the fluid interfering with diffusion of the taste substances into the sensory receptors. That is, the texture of the liquid was partially responsible for the quantity of sapid material that could reach the taste buds over a specific time.

As a result of experiments conducted to determine the effect of texture differences on perception of tartaric acid, sucrose, caffeine and sodium chloride, Mackey and Valassi (1956) reported that the texture of the food affected the facility with which sweet, sour and salt substances were detected. Taste substances were mixed with two foods,

tomato juice and milk-egg custard both with added gelatin, and prepared as liquid, foam or gel. Results showed that added taste substances were most difficult to detect in the gel state and least difficult to detect in liquid form. Also, threshold values were lower for water solutions of the taste substances than for the foods containing the same substances.

Subsequent to this, Mackey (1958), in exploring the effect of solvent medium on taste perception of caffeine, quinine and saccharin, found that the taste substances were more easily detected when dissolved in water than in peanut oil or an aqueous sol of methylcellulose. Since both the methylcellulose sol and the oil mixture were of the same viscosity, it seems unlikely that viscosity alone accounted for all the masking which occurred. In an effort to explain the difference in masking between the lipid and methyl-cellulose mixtures, the author suggested that the difference in perception was due to the fact that substances in lipid solution did not penetrate to the taste receptors as readily as they did when dissolved in water.

In 1966, Stone and Oliver reported decreased sensitivity with increasing viscosity for all panelists involved in an experiment done to determine the effect of viscosity on sweetness detection. Aqueous sucrose solutions with and without added cornstarch or carboxymethylcellulose (CMC) were evaluated for sucrose thresholds. Results

indicated that the panelists were most sensitive to sucrose in plain water and least sensitive to sucrose in a solution containing CMC. Addition of cornstarch resulted in only a slight decrease in sucrose perception. The reasons suggested for this apparent taste masking were that the hydrocolloid interfered with sweetness perception by coating the tongue or that it slowed down the rate of release of sucrose into the mucous bathing the receptor sites.

Vaisey et al. (1969) suggested that, on the basis of the findings of Mackey (1958), Mackey and Valassi (1956) and Stone and Oliver (1966), systems showing more shear thinning in the mouth would facilitate taste perception. They showed that time required for sweetness recognition varied with the shear thinning tendency of the hydrocolloid used. Perception was significantly ($P < 0.05$) more rapid with cornstarch sols which thin rapidly with shear, than with CMC sols which exhibit a slower shear thinning rate. Trends in all their sensory tests suggested that hydrocolloids that had slower shear thinning rates tended to mask sweetness perception.

Moskowitz and Arabie (1970) proposed a function

$$T = kV^n$$

to relate solvent viscosity to taste intensity magnitude. In this equation, "T" represents taste intensity, "V" is the apparent viscosity in centipoises, "k" is a constant and "n" determines the rate at which taste intensity is decreased by

apparent solvent viscosity. Using sodium CMC, these authors showed "n" to vary between 0.05 and 0.20. This power function has a negative slope which indicates decreasing intensity of taste perception with an increase in solvent viscosity. A similar power function relating concentration to magnitude of taste intensity was also proposed,

$$T = kC^n$$

in this case "C" represents the concentration of the taste substance in the mixture. The exponent "n" for sugars has been reported to be 1.3 to 1.5 (Moskowitz and Arabie, 1970) while "n" for artificial sweeteners such as cyclamates falls in the 0.6 to 0.85 range (Moskowitz, 1970).

The fact that both sweetness and viscosity appear to conform to this power function may be useful in explaining taste-texture interactions. In fact, Moskowitz and Arabie (1970) suggest that these equations may be of use for assessing the effect hydrocolloids have on taste perception and that "n," an index of masking ability of the hydrocolloid, could be used to classify the different effects these have on each of the four basic modalities. In addition, by comparing the relative values of "n" for different gums, they state that it may be possible to quantify the relationship between taste-masking and shear thinning proposed by Vaisey and co-workers (1969).

Thus, it appears that the phenomenon of taste-masking does exist in sols of hydrocolloids and hence, it

seems likely that hydrocolloid gels would exhibit a similar effect. In fact, Mackey and Valassi's (1956) work suggests that taste-masking does exist in gels as well as in sols. To the present, however, little other work seems to have been undertaken to substantiate this.

As the work of Vaisey et al. (1969) demonstrated that the degree of masking of sols varied with their mouth-feel properties, it seems reasonable that taste-masking effects of gels might also vary with their rheological behavior in the mouth. Gels from different hydrocolloids are known to differ in texture. Verbal descriptions of visual characteristics of the texture of gels of various hydrocolloids are relatively common. Carrageenan forms a thick and mucilagenous gel which becomes rigid at high concentrations and agar forms a rigid, short, transparent gel (Anon., 1964). Gelatin gels are described as transparent, firm but springy and quivery (Anon., 1964), gels of cornstarch as cloudy to opaque, firm, semi-rigid and short (Anon., 1958) and low methoxyl pectin (LMP) gels as brittle, with clarity depending on the amount of LMP used in the gel (Owens et al., 1949; Lopez and Li, 1968). Objective measurements of hydrocolloid gel differences, however, are scanty. Kramer and Hawbecker (1966) reported force-distance curves from the Allo-Kramer Shear Press for a variety of fruit jellies and CMC gels. Textural differences were obvious from the different patterns of these curves. Work

done by Henry and Katz (1969) with the Instron also indicated textural differences such as springiness among soft gels of guar gum, locust bean gum and pregelatinized tapioca. In a later attempt to relate sensory descriptions of textural differences to instrumentally-measured differences these authors studied a series of semi-solid commercial desserts containing various hydrocolloids such as gelatin and cornstarch (Henry et al., 1971). Using factor analysis they found four areas of sensory textural description: firm and frangible, stringy and sticky, fat-like, and grainy, which accounted for more than 90% of the variation in sensory ratings. They were further able to establish multiple regression equations to predict these factors by means of the instrumental test values.

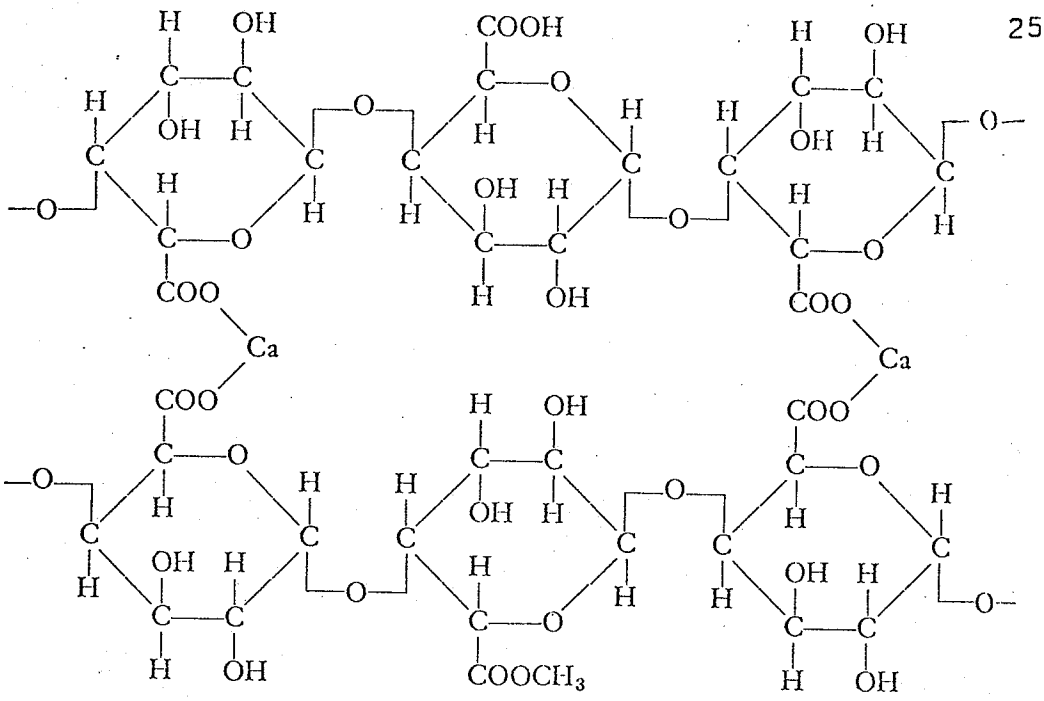
Although many of the textural differences noted among hydrocolloids may be attributed to concentration of the hydrocolloid used, methods of preparation, additional ingredients and temperature of gelled products during production and testing, the intrinsic nature of gelation of each hydrocolloid must also be involved.

Most hydrocolloid gels are formed by some system of bond formation. Hydrocolloids such as gelatin, cornstarch and agar, use hydrogen bonding as their mechanism of gel formation (Fox and Cameron, 1961; Meyer, 1960; Upham, 1966), while LMP and carrageenan require the presence of cations such as potassium or calcium to facilitate gel formation

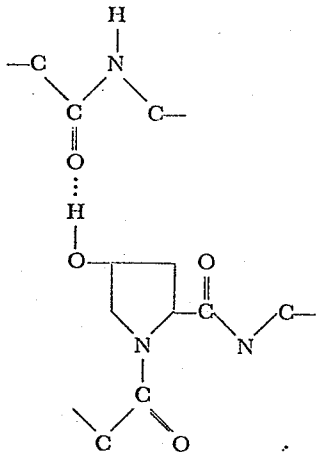
through ionic bonding (Griswold, 1962; Schachat and Raymond, 1960). Figure 6 shows proposed mechanisms for the hydrogen bonding of gelatin and ionic bonding of LMP. Since sweetness perception appears to be the result of hydrogen bond formation between the sweet substance and taste receptors in the tongue (Dastoli and Price, 1968), taste-masking could result if hydrocolloids were bonded to some of the receptor sites in place of the taste substance. That is, taste-masking might be the consequence of competition between the hydrocolloid and the sweet substance for hydrogen bonding to either the AH or B site of the taste receptors in the tongue.

The fact that sols which thin rapidly with shear, taste sweeter (Vaisey et al., 1969) suggests alternately that sweet substances might hydrogen bond to the hydrocolloid. As the hydrogen bonds are broken by shearing action, the sweet configuration would be available for the tongue receptor and sweetness would be obvious. Following this theory, gels which reduce more rapidly in the mouth might be expected to taste sweeter, as sweet molecules would be more readily available for reaction with the tongue. In the case of ionically bonded gels, sweet substances would not be hydrogen bonded to the hydrocolloid and thus sweetness of these gels would be perceived more rapidly than with hydrogen bonded gels.

Accordingly, the present research was done to see



Ionic Bonding in Low Methoxyl Pectin (Griswold, 1962)



Hydrogen Bonding in Gelatin (Veis, 1964)

Figure 6. Examples of Ionic and Hydrogen Bonding Occurring in Gels During Gelation

if sweetness perception in gels of various hydrocolloids did have any dependence upon their textural characteristics and if so, to determine whether this could be predicted instrumentally from the physical parameters measured with a Texturometer.

METHOD

Five hydrocolloids: carrageenan (Carra), low methoxyl pectin (LMP), agar, gelatin and cornstarch (CS), were prepared as gels, similar in hardness and containing equal amounts of artificial sweetener. The relative sweetness of these gels was assessed by a 7-member trained sensory panel and considered in relation to their instrumentally-described textural characteristics. Four replications of this experiment were carried out.

This experimental work may be considered in two sections, a) standardization of the gels to comparable hardness and b) examination of perceived sweetness in relation to textural properties.

Standardization included recipe manipulation of hydrocolloid proportions to yield gels of similar hardness as determined from instrumental readings. Later observations of variability in hardness between replications suggested that it was necessary to determine whether the hardness differences noted instrumentally could be perceived by sensory means. This question was examined only with gelatin, the hydrocolloid most familiar to untrained judges and easiest to control during preparation and testing.

Gel Preparation

To allow for both sensory and instrumental

measurements, gels were prepared in 750 ml lots using the proportions indicated in Table 1. These proportions were used since they were shown to produce gels of similar hardness as determined by preliminary Texturometer testing. The gels produced were of medium firmness, slightly more rigid than commercially produced desserts.

For sensory examination of hardness the following concentrations of gelatin were used:

least hard	A	3.560 gm/100 ml tap distilled water
	B	3.587 gm/100 ml tap distilled water
hardest	C	3.613 gm/100 ml tap distilled water

All hydrocolloid mixtures were prepared in 2-quart Pyrex coffee pots using a household-type gas range. Mixtures were set in open-ended metal tins[1] 8.69 cm in height and 52.0 mm in diameter. These tins were fitted with metal collars of the same diameter, secured to the tins with rubber tubing (2.54 cm wide). These collars permitted overfilling the tins to 4 cm which was necessary to compensate for shrinkage during gelling. The lower ends of the tins were covered with 8 cm squares of plastic film[2] held in place with elastic bands. The 750 ml preparation lot yielded 3 tins of gel. Preparation of 2 lots per gel provided samples for sensory and instrumental testing.

---

[1] Sun Rype brand, individual portion tins.

[2] Saran Wrap, Dow Chemicals Ltd., Montreal.

Table 1. Proportions of Ingredients for Gel Preparation

Ingredient \ Gel	Carra[1]	LMP[2]	Gelatin[3]	Agar[4]	CS[5]
Hydrocolloid (gm)	1.430	1.333	3.587	0.433	9.987
Water (ml) - tap distilled	100	100	100	100	100
Na Sucaryl[6] (ml)	0.667	0.667	0.667	0.667	0.667
Additional chemicals		0.117 gm[7] citric acid 5 ml $CaCl_2$[8] solution			

[1]Pectin, L.M. No. 3466/U 136 gel power. Sunkist Growers, Inc., Corona, California, 91720, USA.

[2]Calcium carrageenan, Sea Kem 14, Marine Colloids Ltd., Springfield, N.J.

[3]Agar (pooled from Stein Hall & Co. and Duché Uni-gum). Duché Products division/Stein, Hall & Co. Inc., 605 Third Ave., New York, N.Y., 10016.

[4]Gelatin, Davis Gelatine (Canada) Ltd., Montreal, Toronto, Vancouver.

[5]Cornstarch, Durham Corn Starch, St. Lawrence Starch Co. Ltd., Port Credit, Ontario.

[6]Sucaryl Sodium, Abbott Laboratories Ltd., Montreal. 8% sodium cyclamate and 0.8% sodium saccharin.

[7]Citric acid, Reagent, A.C.S., Powder. Matheson Coleman & Bell, Ohio, USA.

[8]$CaCl_2$ solution. 12 gm $CaCl_2$(anh) 946 ml tap distilled water.

Preparation methods for the individual gels were as follows.

LMP, Carrageenan and Cornstarch

These hydrocolloids were dispersed gradually into cold water containing sodium Sucaryl and brought to a full rolling boil over maximum heat with constant stirring. Because LMP and carrageenan showed a distinct tendency to lump upon addition to water, they were added through a fine metal sieve and the water was kept in constant motion by the use of an electric hand beater set at medium speed. Following heating, the carrageenan sol was poured immediately into the prepared tins. Calcium chloride solution was combined with the LMP sol using an electric mixer for 10-15 seconds, then this mixture was poured into the gel molds. Cornstarch was held boiling for 2 minutes before pouring.

Agar

Agar gels were prepared by bringing the specified quantity of water and sodium Sucaryl to a boil, dispersing the hydrocolloid in this solution and bringing the mixture back to a full rolling boil with constant stirring. Following this procedure, the hot mixture was poured immediately into prepared tins.

Gelatin

The gelatin was hydrated for 5 minutes in one-fifth of the total quantity of water specified, then combined with boiling sodium Sucaryl solution and stirred until the gelatin

was completely dispersed. The resulting liquid was immediately poured into prepared molds.

After preparation, all gels were allowed to set at room temperature for 7 hours. Then they were refrigerated at 6°C until they were tested on the following day at the age of 27 to 29 hours.

Sampling

Using a metal mitre box, gel samples of tin diameter and 1.27 cm in height, were cut from each tin and identified as shown in Figure 7. This was accomplished by removing the metal collar and plastic film from the tin and sliding the gel out of the bottom of the mold and into the mitre box. Section 1 was always discarded as it was often damaged during removal of the plastic film and because it had only one cut surface. Sections 4 were always used for instrumental measurement, while 2 and 3 were reserved for sensory analysis where $\frac{1}{4}$ of a section served as an individual sample. In the tests of gel sweetness, panel numbers were smaller than for the sensory hardness experiment thus permitting the use of sections 2 and 3 from one tin per lot for instrumental measurement as a check of gel uniformity throughout the tin.

Gel sampling was done 2 hours prior to panel time and samples were then refrigerated until needed. During sampling, gels were kept as cool as possible by storing them in the refrigerator before and after sampling to limit the

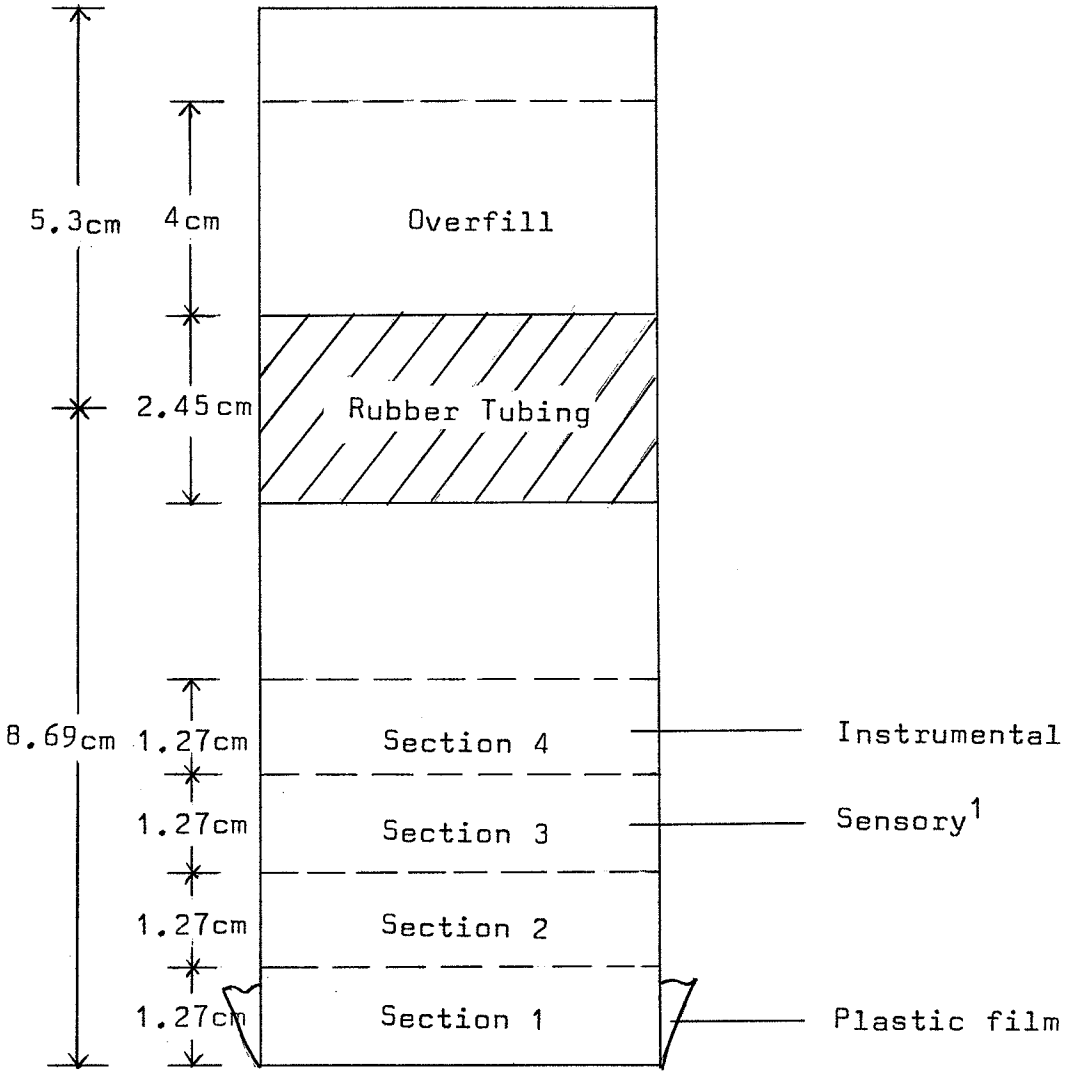


Figure 7. Identification of sections from one tin of gel

[1]In gel lots prepared for sweetness perception tests, these sections from one tin per lot were also tested instrumentally.

occurrence of any temperature dependent changes.

Texture Assessment

Instrumental Measurements

Instrumental measurements were made using a General Foods Brabender Texturometer fitted with a 50 mm diameter nickel plunger and a 94 mm diameter aluminum cup. A clearance of 6 mm was allowed; chart speed was set at 750 mm per minute and 2 consecutive chews were made at a speed of 12 chews per minute. Voltage of 2.5 or 3 volts was used depending on the hardness of the gel samples.

A complete gel section served as the sample for one Texturometer reading. Textural characteristics of the hydrocolloids were assessed on 12 samples of each gelatin concentration in the hardness experiment (1 section from each of 3 tins x 2 lots x 2 replications), and on 40 samples of each hydrocolloid in the main experiment assessing relative sweetness (5 sections [3 of #4 plus 1 each of #2 and #3] per tin x 2 lots x 4 replications).

Results for hardness, cohesiveness, springiness, chewiness and gumminess measured, were calculated as in Figure 4. For this particular machine C, the constant for an inelastic material was found to be 68 mm. In some cases the pen did not return to the original base line following the first and/or second chew. This was due to adhesion of some of the sample to the plunger surface during chewing action.

When this occurred, measurements were made using an adjusted base line. This line was determined by drawing a straight line which would connect the original base line and the new base line, from points at the beginning and end of peak. In all such cases, the difference between the original and new base lines was no greater than 2 mm in height.

Analyses of variance were applied to determine within parameter differences among gels within replicates, differences among replicates and existing interactions. Estimation of sampling and experimental errors were also made within each instrumentally measured parameter in these analyses.

Sensory Measurement of Hardness

A total of 47 panelists judged 3 concentrations of gelatin for relative hardness on the 2 replicates of the gel preparation.

Sensory testing was carried out in a small, relatively noise-proof, 5-booth sensory testing room. Yellow lights were used to mask color differences observed in gels during preliminary work. Gels were prepared and sampled using the methods previously described.

Using a multiple paired comparison method, each panelist assessed the relative hardness of the 3 gelatin concentrations by examining 3 pairs (AB,AC,BC) of the sweetened gelatin samples. Sample order was balanced within pairs and pair order was randomized for each replicate

(Larmond, 1967). Figure 8 shows the questionnaire used for this panel and Figure 9, the instructions given to the judges.

Results for each replicate were assessed using a computer program for paired comparisons (no ties) developed by the Statistical Research Service of the Canadian Department of Agriculture, Ottawa (Petrasovits and Clark, 1969) and adapted to be run on an IBM 360 computer (Appendix). In addition to calculating chi-square values for test of treatment differences and test of agreement of panelists, this program extends the technique of Terry et al. (1952) on which it is based, to permit analysis of treatment means by Tukey's test. This method of handling data involves assigning a value of 1 to the member of the pair judged to have more of the attribute under study and a value of 2 to the other member. The total number of observations yielded per treatment per judge in 1 replicate, is equal to the total number of treatments tested minus 1. For example, in comparing the 3 gelatin concentrations with 47 judges, the total number of observations per concentration equalled $47 \times 2 = 94$.

Assessment of Apparent Sweetness

To determine the presence of taste-texture interactions, the five hydrocolloid gels were tested for relative sweetness by a panel of seven selected and trained judges

in a series of four replicated multiple paired comparison trials. Selection, training and testing for sweetness perception were conducted under the physical conditions previously described.

Panel Selection

A group of fifteen staff and students from the

PAIRED COMPARISON DIFFERENCE

NAME _____ DATE _____

For each pair taste samples in order listed and circle the one which is harder.

Samples _____

_____

Figure 8. Questionnaire Used by Sensory Hardness Panelists

HARDNESS: the force required to compress the gel until it splits initially.

1. In judging, use tongue-to-palate pressure, that is, place sample of gel on tongue and press it against roof of mouth. Determine the force you need just to split the gel.

2. Do <u>not</u> swallow gels. Containers are provided for expectoration.

Figure 9. Instructions Provided for Sensory Hardness Panelists

Department of Foods and Nutrition, was tested for accuracy of sweetness perception with paired sodium Sucaryl solutions of varying concentrations similar to those used in the gels.

For each selection session, each candidate was given two sets of three pairs of sodium Sucaryl solutions: AB, AC, BC (Table 2) and asked to indicate which sample of each pair was sweeter. Figure 10 shows the questionnaire used for this panel. Figure 11 indicates directions given to panelists to be followed during testing.

Order of sample presentation within each pair was balanced and order of pairs within each set was randomized. Set 1 was always presented first since differences between the samples were greater and served to re-orient panelists each day. Individual performance was assessed and reported to each judge immediately following each set.

Results from 3 to 5 of these selection tests (9-15 paired comparisons) were plotted for each panel candidate. Using a method of sequential analysis (Amerine et al., 1965) with limits such that those with less than 55% correct were rejected while those with 75% or more correct were accepted, eight panelists were selected to assess the relative sweetness of different hydrocolloid gels. Only the results from seven of the panelists were used, however, as the eighth panelist was present for only two of the four gel replications.

Table 2. Sodium Sucaryl Concentrations Used for Sweetness Panel Selection (ml Na Sucaryl/100 ml tap distilled water)

Set 1		Set 2	
A	0.667	A	0.667
B	0.640	B	0.647
C	0.613	C	0.627

PAIRED COMPARISON DIFFERENCE

NAME _____ DATE _____

You are receiving paired samples to compare for sweetness. For each pair taste samples in order listed, circle the one which is sweeter.

Samples _____ _____ _____ _____ _____ _____

_____ _____ _____ _____ _____ _____

Figure 10. Questionnaire Used for Selection and Training of Sweetness Perception Panelists

1. Do not swallow solutions, containers are provided for expectoration.

2. Between pairs - eat a cracker and rinse with milk or water. Crackers and rinsing materials may be expectorated if desired.

Figure 11. Instructions for Sweetness Perception in Solutions

Panel Training

Panel selection trials also served as training for sweetness perception. Brief retraining immediately prior to each gel tasting session was accomplished with the use of sweetened solutions. The eight panelists, selected on the basis of their accuracy in sweetness perception, were presented with three pairs of sodium Sucaryl solutions at the levels of Set 1 as shown in Table 2. Results of this exercise were scored and panelists were informed of their results before they were presented with five pairs of gels to judge. Sodium Sucaryl solutions thus were used to reorient panelists to the approximate level of sweetness they would find in the gels, to motivate panelists and to serve as a check on their accuracy. Order of presentation of pairs of solutions was random.

Panelists' results for sodium Sucaryl solution testing were plotted as a continuation of the sequential analysis graphs used for selection, to assess the sweetness perception accuracy of each panelist during examination of gel sweetness.

Sweetness Perception in Gels

A multiple paired comparison method with a balanced arrangement of samples within pairs (Larmond, 1967) was used for sweetness testing of gels. Judges received a total of ten pairs of samples over a two-session period (Table 3). During the first session, half the panelists tasted five of

Table 3. Typical Gel Sample Presentation Order for One Judge for One Replicate of the Sweetness Perception Experiment

Hydrocolloid		Pairs Tested	
Code	Name	Session 1	Session 2
A	LMP	BC	AD
B	Carra	EC	BD
C	CS	EB	ED
D	Gelatin	BA	CD
E	Agar	AC	EA

the ten pairs of gel samples while the second half of the panelists tasted the remaining five pairs of samples. In the second session, the procedure was reversed. For each of the four replicates, order of pair presentation and sample order within pairs was random.

Figure 12 shows the questionnaire used for this panel and Figure 13, the additional instructions given to panel members.

Analysis of Results

Results from the four replicates of gel testing were analyzed for significant sweetness differences using a computer program (Petrasovits and Clark, 1969) for paired comparisons (no ties). In this case, the total number of observations per treatment per replicate, based on 7 judges and 5 hydrocolloids, was 28.

An analysis of covariance and multiple correlation coefficients were applied to the mean treatment scores for the four replicates of the sweetness panels and Texturometer results run concurrently on gel samples to determine whether an instrumentally measured parameter could be used to predict taste-texture interactions.

PAIRED COMPARISON DIFFERENCE

NAME _____ DATE _____

For each pair taste samples in order listed and circle the one which is sweeter.

Samples _____

_____

Figure 12. Questionnaire Used for Sensory Sweetness Perception Testing of Gel Samples

1. Do not swallow gels. Containers are provided for expectoration.
2. Rinse between pairs but not between samples within a pair.
3. Use spoons when sampling gels.

Figure 13. Instructions for Sweetness Perception of Gels

RESULTS AND DISCUSSION

Textural Characteristics of Gels

Texturometer curves representative of those derived from the 5 hydrocolloids tested are illustrated in Figures 14a, b, c, d and e. As is shown by these Figures, the Texturometer was able to assess such parameters as hardness, cohesiveness, springiness, chewiness and gumminess in these gels, however, brittleness and adhesiveness were not detected. Accuracy of this instrument is verified by the fact that experimental error, a measure of variation within gels between the 2-lot preparations for each session was not significant (Table 4) for 4 of the 5 textural parameters measured.

With the exception of hardness, all textural parameters measured instrumentally, differed significantly at the 1% level among the 5 hydrocolloids tested. Mean squares and F values used to test each of these parameters are shown in Table 4.

To consumers, hardness is the most commonly recognized of the various textural parameters (Yoshikawa et al., 1970). For this reason, gel proportions were originally calculated to produce products in which differences in hardness were minimized so that effects of the other textural parameters on taste perception would not be overshadowed by

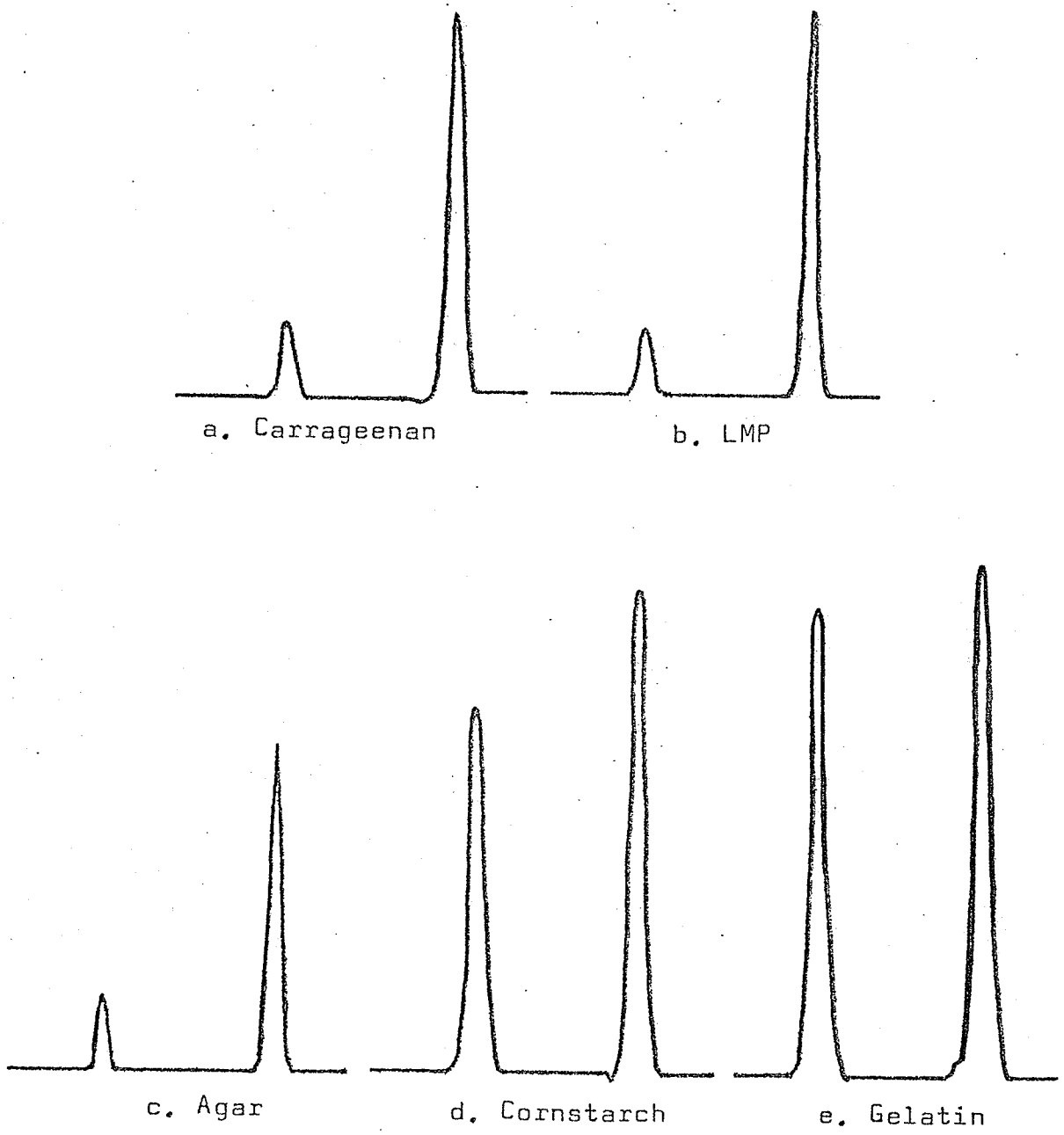


Figure 14. Representative Texturometer Curves of the 5 Hydrocolloids Tested

Table 4. Summary of Analyses of Variance of Instrumental Data

Source	df	F values and MS from Anovas				
		Hardness	Cohesiveness	Springiness	Chewiness	Gumminess
F Values						
Replicates	3	0.71	1.682	1.949	0.829	0.983
Treatments	4	5.29*	292.554**	115.886**	70.179**	287.516**
RxT Interaction	12	3.07*	1.923	0.339	0.960	1.217
Expt Error	20	2.57**	1.016	0.758	1.157	1.578
Mean Squares						
Interaction[1]	12	304.323	0.0160	0.612	6286.33	59.620
Expt Error[2] (between sessions)	20	98.909	0.0084	1.805	6544.80	48.970
Sampling Error[3] (between samples)	160	38.452	0.0083	2.380	5655.29	31.030

* $P < 0.05$ ** $P < 0.01$

[1] used to test replicates and treatments.

[2] used to test interaction.

[3] used to test experimental error.

hardness differences. The differences among treatments for hardness were significant at the 5% level of probability. Tukey's test ($P<0.05$) applied to hardness means (Table 5) indicated the following arrangement of treatments:

Gelatin Cornstarch Carrageenan Agar LMP

Further evidence of variability in hardness of the gels is shown by the significant interaction between treatments and replicates (Table 4). This suggests that the differences in hardness between gels were not constant over all replicates and examination of the interaction indicated that most of the variability in hardness values occurred among cornstarch and agar. Significant experimental error also shows that there was appreciable variability in hardness within any one gel over the two-day period involved in one replicate, despite rigorous control of experimental conditions.

Specific differences among gels within each parameter may be considered from the mean values of the instrumental measurements shown in Table 5. In considering only those differences significant at the 1% level of probability, gelatin and cornstarch were shown to be significantly more cohesive, springier, chewier and gummier than carrageenan, LMP and agar.

Cohesiveness is a measurement thought to be related to the strength of the internal bonds of the molecular structure of the foodstuff being tested (Friedman et

Table 5. Mean Texturometer Values for Gels[1]

Parameter \ Gel	Carra	LMP	Agar	Gelatin	CS	Standard Error
Hardness (mm/volt)	49.54[a]	44.23[a]	46.27[a]	60.20[a]	53.75[a]	2.758
Cohesiveness (cm^2)	0.208[b]	0.214[b]	0.176[b]	0.867[a]	0.791[a]	0.02
Springiness (mm)	2.825[b]	1.450[c]	1.775[c]	4.200[a]	4.432[a]	0.1237
Chewiness	29.570[b]	17.576[b]	16.309[b]	218.051[a]	206.995[a]	12.536
Gumminess	10.32[c]	9.50[c]	8.28[c]	51.34[a]	41.95[b]	1.221

[1] mean of 40 observations/treatment (10 x 4 reps)

[abc] numbers in same row bearing different superscripts are significantly different ($P < 0.01$) based on Tukey's hsd test. a = largest mean of set.

al., 1963; Szczesniak, 1966b). The observation that gelatin and cornstarch were more cohesive may be due to the fact that these gels are hydrogen bonded (Fox and Cameron, 1961; Mayer, 1960) while LMP and carrageenan are ionically bonded to form gels (Griswold, 1962; Schachat and Raymond, 1960). Force applied to gelatin and cornstarch would therefore result in breaking of hydrogen bonds which although weak, also reform rapidly. The same force applied to ionically bonded carrageenan and LMP would not break these bonds as easily, but once broken, they will not be readily reformed. Thus gelatin and cornstarch would appear to be more cohesive than carrageenan and LMP. Despite the fact that agar is hydrogen bonded, it appeared more like carrageenan and LMP in cohesiveness than like gelatin and cornstarch.

Springiness patterns for the hydrocolloids tested were similar to the differences noted in cohesiveness with one exception. Although gelatin and cornstarch were springier, or more elastic than the other gels, carrageenan was significantly springier than LMP and agar (Table 5).

Since springiness is effectively a measurement of the amount of recovery from an applied force that a foodstuff exhibits over a specific time, it is to be expected that a more cohesive product would show a greater degree of springiness than one which recovered slowly if at all, from an initial application of force. This was quite clearly seen during actual testing of gel samples. Agar gels gave

a clean split during application of force of the Texturometer plunger, while LMP gels usually split at an angle and carrageenan gels showed plunger indentation marks and some splitting about the edges. Gelatin, on the other hand, showed no visible evidence of damage to the gel sample following plunger pressure, and cornstarch gels showed slight, if any, plunger indentations.

Chewiness of a foodstuff is expressed as the product of the three primary parameters, hardness, cohesiveness and springiness (Friedman et al., 1963). Since differences for cohesiveness and springiness were significant in the same direction and since hardness differences among gels were not significant at the 1% level of probability, differences in chewiness would be expected to be of the same nature as those parameters of which it is a product. As can be seen from Table 5, gelatin and cornstarch are again significantly different from carrageenan, agar and LMP.

The parameter gumminess is also expressed as a product of primary parameters, in this case, hardness and cohesiveness are used. Analysis of gumminess for the different gels showed gelatin to be the most gummy and significantly ($P < 0.01$) different from the other four gels. Cornstarch was the next gummiest and was significantly different from carrageenan, LMP and agar.

In general then, when prepared to be of hardness similar to that encountered in gelled desserts, cornstarch

and gelatin were similar in all parameters except gumminess where cornstarch was significantly less gummy. Relative to gelatin and cornstarch; agar, LMP and carrageenan were less cohesive, springy, chewy and gummy. Of these 3 hydrocolloids, carrageenan was significantly springier although still less elastic than gelatin and cornstarch.

Because hardness differences, measured by the Texturometer, were significant at only the 5% level of probability, whether or not they would be perceptible by sensory panelists seemed questionable. However, untrained tasters were able to detect controlled differences in gel hardness (Table 6) comparable to differences in hardness among all hydrocolloid gels (Table 5). Analysis of variance of Texturometer hardness from these data indicated significant treatment differences ($P < 0.01$) with the least hard gel being significantly different from the other two. Differences among sensory judgements of hardness for the 3 gelatin gels were also significant ($\chi^2 = 11.17$ with 2 df) with the gel containing the least amount of gelatin being significantly ($P < 0.004$) less hard than the other two levels. The results of these sensory and instrumental tests, then, suggest that untrained judges could pick out the hardness differences in gels identified by the Texturometer. Furthermore, hardness differences noted among the different hydrocolloid gels (Table 5) could be expected to be recognizable by sensory judges and would have to be considered in any

Table 6. Sensory and Instrumental Measurements of Gelatin Hardness Differences

Measure of Hardness	Least Hard 3.56% gelatin (w/v)	Medium Hard 3.59% gelatin (w/v)	Hardest 3.61% gelatin (w/v)	Standard Error
Texturometer[1] values (mm/volt)	44.22[b]	53.38[a]	55.13[a]	2.39
Sensory scores[2] (lowest = hardest)	3.34[b]	2.85[a]	2.81[a]	0.1755

[1] mean values from 12 observations/treatment.

[2] mean values from 94 observations/treatment.

[abc] numbers in same row bearing different superscripts are significantly different ($P < 0.01$ for Texturometer means and $P < 0.004$ for sensory panel).

taste-texture interactions observed.

Sensory Perception of Sweetness

Selection and retraining sessions with Sucaryl solutions showed that the panelists, selected at the 75% level of accuracy, maintained a high degree of accuracy in sweetness perception during the period that they were examining the relative sweetness of the different hydrocolloid gels. A comparison of Figures 15a and 15b shows the contrast in correct judgements between accepted and rejected panelists during the selection tests. Figure 15a also shows that with the exception of judges d and e, all accepted panelists continued to operate at or above the 75% level of accuracy in discriminating differences of 0.027% sodium Sucaryl in two-thirds of the paired solutions and of 0.054% in the remaining one-third of the samples. Both judge d and judge e were absent from some of the selection sessions and thus had not reached the 75% level of accuracy by the point at which the gel tasting sessions commenced. However, because they had maintained an adequate level of performance during the selection tests, the decision was made to include them as a member of the sweetness perception panel. Judge d proved to be an acceptable judge since her performance continued to improve until, by the end of the gel tasting sessions, she had reached the 75% level of accuracy. Analysis of sweetness perception data from which judge e's results

were excluded, did not change the interpretation of results, therefore, her data was retained and was included in the analysis of sweetness perception panel results.

Although sodium Sucaryl concentrations were identical among the hydrocolloid gels, there was a significant difference in apparent sweetness among them (Table 7). In general, the pattern of differences was the same for each of the four replications lending further confidence to the

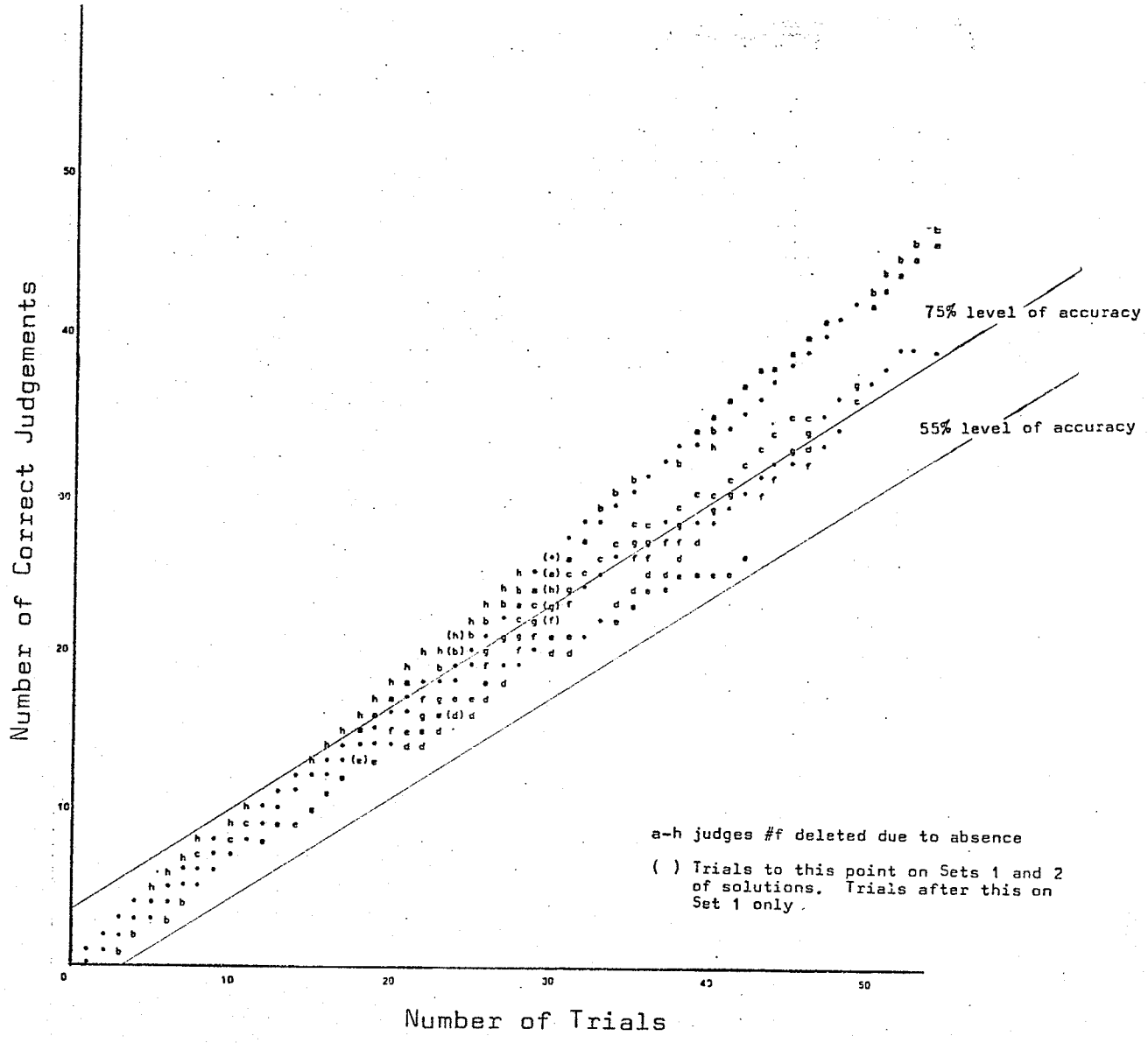


Figure 15a. Performance of Successful Panel Candidates in Perception of Sweetness Differences

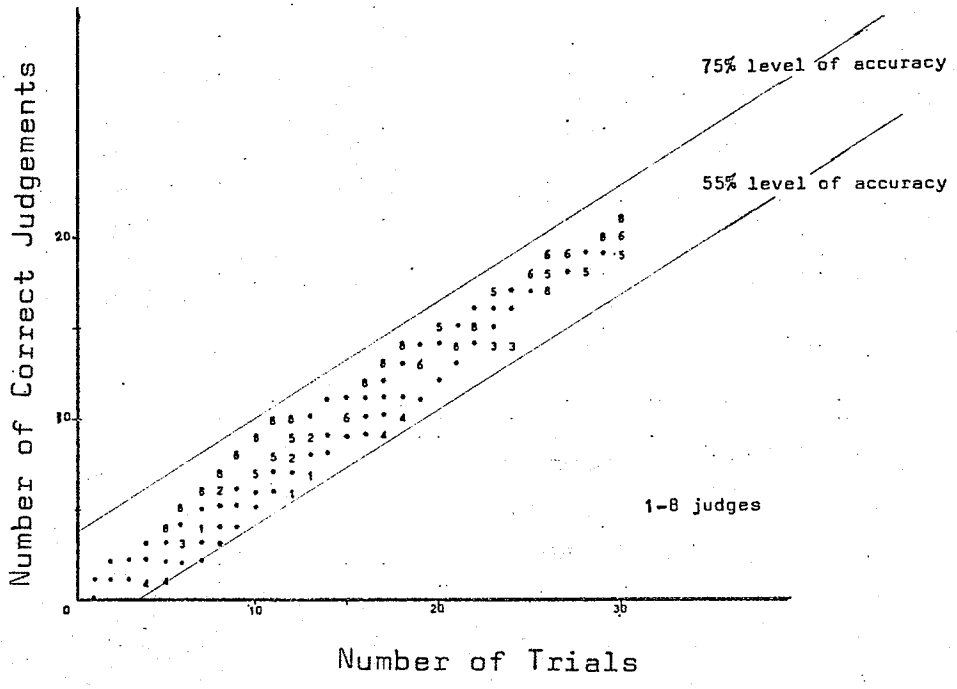


Figure 15b. Performance of Unsuccessful Panel Candidates in Perception of Sweetness Differences

Table 7. Mean Sweetness Scores for Gels[1]

Rep \ Gel	Carra	LMP	Agar	Gelatin	CS	Avg. Stnd. Error[2]	χ^2_{2df}
1	4.71^{a}	5.14^{ab}	5.86^{abc}	6.57^{bc}	7.71^{c}	0.5114	38.78
2	4.86^{a}	5.14^{a}	6.00^{ab}	6.43^{ab}	7.57^{b}	0.4534	30.68
3	4.57^{a}	5.57^{ab}	5.57^{ab}	6.57^{ab}	7.71^{b}	0.5133	38.93
4	4.43^{a}	5.86^{ab}	5.86^{ab}	6.57^{b}	7.28^{b}	0.4485	29.34
Mean of all reps	4.64^{a}	5.43^{ab}	5.82^{b}	6.54^{b}	7.57^{c}	0.2320	131.05

[1] mean values from 28 observations/treatment; lowest score = "sweetest" gel.

[2] average standard error of Log P(i) as determined by computer program for paired data (Petrasovits and Clark, 1969).

[abc] numbers in same row bearing different superscripts are significantly different ($P < 0.01$) based on Tukey's hsd test.

differences which were significant at the 1% level of probability. Carrageenan was always the sweetest and cornstarch was always the least sweet.

LMP, agar and gelatin were shown to be intermediate between carrageenan and cornstarch despite the fact that LMP required the addition of citric acid for gelling and was reported by some panelists to taste "sour." In reviewing the literature dealing with taste interrelationships, Pangborn (1960) noted many conflicting results on the relationship between sweetness and sourness. She indicated that citric acid had been suggested to have an enhancing effect on sweetness of sucrose, a diminishing effect on sweetness of fructose and no effect on sweetness of fructose. More recently, Moskowitz (1971) reported that addition of a second taste modality had little, if any, effect on perception of the primary taste substance. In fact, the percentage changes in exponent from the primary modality to a mixture of two modalities was always less than 25%, which is similar to the variation of the exponent observed when a single taste is judged in several different experiments. It is unlikely therefore, in this experiment, that addition of the citric acid affected the sensory perception of apparent sweetness in the LMP gels.

The observed order of gels, then, from sweetest to least sweet on the basis of the overall averages is as follows:

Carrageenan > LMP > Agar > Gelatin > Cornstarch

The presence of significant differences in apparent sweetness of these hydrocolloid gels serves as an indication of the existence of taste-masking. This further supplements the findings of Mackey (1958), Stone and Oliver (1966) and Moskowitz and Arabie (1970), all of whom reported the occurrence of taste-masking in sols of various hydrocolloids and of Mackey and Valassi (1956) who noted its occurrence in gels. Further, gels which were less elastic, less chewy and less gummy and thus likely to break down more rapidly in the mouth, tended to be sweeter. This observation concurs with the implications of work reported earlier by Vaisey et al. (1969) which showed that sols which shear more rapidly tend to taste sweeter than those which remain thick longer.

The suggestion has been made in the review of literature that taste-masking in gels could be linked to the method of bonding during gel formation, or to hydrogen bonding of the sapid material to the hydrocolloid. In the light of these results, both these hypotheses seem reasonable in that the ionically-bonded gels, carrageenan and LMP, were perceived by panelists to be significantly sweeter than gelatin and particularly cornstarch, both of which rely on hydrogen bonding as the mechanism of gelatin.

A summary of the analysis of covariance applied to the relative sweetness scores and the texture measurements from gels tested at the same time is shown in Table 8.

Table 8. Summary of Analysis of Covariance of Sweetness Scores and Textural Measurements

Source		df	SS	MS	F
Error	Total	12	0.7091		
	Regression	5	0.2447		
	Deviations	7	0.4644	0.0663	
Trts + Error	Total	16	20.4913		
	Regression	5	14.1520		
	Deviations	11	6.3393		
Adj Trt Means		4	5.8749	1.4687	22.15**

** $P < 0.01$

This method adjusts treatment means of the dependent variable, sweetness, for effects which the 5 independent variables, hardness, cohesiveness, springiness, chewiness and gumminess may exert on them and then tests for differences among these adjusted means. As can be seen from Table 8, the F value for adjusted treatment means was determined to be 22.15 (4 and 7 df) which is significant at the 1% level of probability. This suggests that the differences in sweetness are still significant for the various gels, even after the treatment means have been adjusted for all 5 variables measured instrumentally. The correlation of sweetness with the 5 textural parameters measured, was found to be 0.723. Although this correlation coefficient was not significant, this combination of independent variables explains 52.32% of the differences in sweetness of the gels.

Table 9 shows the correlation coefficients and percentage of variance in sweetness explained by various combinations of the 5 independent variables. From this table it may be observed that the combination of 4 of the 5 predictors from which cohesiveness was excluded, had a correlation coefficient of 0.721 which is very similar to that obtained when all 5 predictors were used. Similarly, when a combination of hardness, chewiness and gumminess were used, "R" was found to be 0.705. This combination explained 49.68% of the variance in sweetness, or almost all that

Table 9. Percentage of Variability in Sensory Scores Explained by Instrumental Data

Predictor	Code	Individual Predictors		Percentage of Variance Explained by and Correlation of Predictors in Different Combinations								
		R	R^2%	2 Predictors			3 Predictors			4 Predictors		5 Predictors
Hardness	X_1	0.136	1.85				X_1		X_1	X_1	X_1	X_1
Cohesiveness	X_2	0.212	4.49		X_2			X_2		X_2		X_2
Springiness	X_3	0.304	9.24	X_3	X_3		X_3				X_3	X_3
Chewiness	X_4	0.140	1.97			X_4		X_4	X_4	X_4	X_4	X_4
Gumminess	X_5	0.115	1.33	X_5		X_5	X_5	X_5	X_5	X_5	X_5	X_5
Total R^2%				15.40	17.64	22.30	30.09	37.29	49.68	49.87	51.97	52.32
Total R				0.392	0.420	0.472	0.548	0.610	0.705	0.706	0.721	0.723

Factors such as the temperature of the mouth and the presence of saliva, which could not be duplicated when testing gels instrumentally, could account for part of the variation in sweetness. Since gels soften and melt at widely differing temperatures e.g. agar at 80-85°C, gelatin at 26.5°C and carrageenan at 27-41°C (Anon., 1964), sample temperature during instrumental testing could certainly have affected measurements of hardness and probably cohesiveness, thereby also affecting apparent chewiness and gumminess. Similarly, differences in sweetness could have been affected by rate of gel melting in the mouth, with those melting more rapidly allowing faster release of the sapid material or more rapid blocking of hydrogen bonding sites on the tongue.

Since visual differences such as color have been found to have an effect on sweetness perception (Amerine et al., 1965), it was felt that color and opacity differences among the gels being tested might affect sweetness perception. The range in color and differences in opacity, varied from cornstarch which appeared as a white, completely opaque gel, through carrageenan which was a pale yellow, cloudy gel to agar, a transparent and virtually colorless gel. An effort to mask these differences was made by the use of yellow lighting during testing, however, this was not totally successful and panelists could still detect differences visually. It is therefore possible, that visual

explained by the 5 predictors used together. Thus it may be possible to predict sweetness differences among gels by looking at a combination of at least 3 of the 5 parameters measured on the Texturometer. Using fewer than 3 parameters, that is, a combination of 2 or an individual textural characteristic, is of little use as at most they account for less than one quarter of the variance in sweetness perception. In most cases where combinations provide an acceptable correlation, either chewiness or gumminess or both are included in the combination. These parameters are both derived from combinations of the primary parameters, thus all the primary ones are included, although indirectly, in the 3 and 4 predictor combinations which are of use in sweetness prediction.

Use of the 5 instrumentally measured textural characteristics to predict sweetness masking may be possible, therefore, as they explain 52.32% of the sweetness differences. Since "R," however, was not significant, further experiments would have to be conducted to determine their true significance as potential predictors. It is possible that with further replication they might be found to explain increasingly greater amounts of the variation in sweetness, however, it is likely that other textural parameters such as the geometrical ones not measured, or experimental conditions, account for a large part of the remaining 47.68% unexplained variation in sweetness.

differences biased sensory perception.

In conclusion then, it appears that panelists detected significant differences in apparent sweetness of equi-sweetened gels. This suggests that taste-masking did occur in the hydrocolloid gels tested. Furthermore, because they explain over half this variation in sweetness, it may be possible to use all 5 textural parameters measured instrumentally to predict potential sweetness masking in gels of this type.

SUMMARY AND CONCLUSIONS

Results of this study showed that hydrocolloid gels of differing textural characteristics varied in their apparent sweetness even though all gels contained 0.67% sodium Sucaryl.

Equi-sweetened gels of similar hardness as measured by the General Foods Brabender Texturometer, contained 1.43% carrageenan, 1.33% low methoxyl pectin (LMP), 0.43% agar, 3.59% gelatin or 9.99% cornstarch. Texturometer curves from two successive 'chews' failed to show any clear evidence of brittleness or adhesiveness. However, differences in cohesiveness, springiness, chewiness and gumminess were significant ($P < 0.01$). Despite careful experimental control, hardness differences ranging between 44.23 and 60.20 mm were detected and found to be significant at the 5% level of probability. Similar hardness differences in gelatin only, were detectable to a panel of 47 untrained judges as well as by instrumental readings ($P < 0.01$).

Gelatin and cornstarch were found to be significantly ($P < 0.01$) more cohesive, springy, chewy and gummy than carrageenan and LMP. Agar was intermediate in hardness, springiness and sweetness and tended to be more like carrageenan and LMP in all 5 textural parameters as well as sweetness.

The relative sweetness of the 5 hydrocolloid gels was examined concurrently with instrumental measurements in 4 replications of a multiple paired comparison test using a 7-member, trained sensory panel. Selected for their ability to detect sweetness differences in aqueous solutions of sodium Sucaryl, these panelists showed 65-75% accuracy in training periods held immediately prior to each gel testing session. Analysis of the data from the relative sweetness comparisons of all 5 hydrocolloid gels showed that cornstarch and gelatin were perceived as significantly ($P < 0.01$) less sweet than the other 3 hydrocolloids. Carrageenan exhibited the greatest apparent sweetness ($P < 0.01$).

Thus, gelatin and cornstarch which were slightly harder and much more cohesive, springy, chewy and gummy than agar, LMP and carrageenan, were also apparently less sweet. Analysis of covariance applied to the sensory and instrumental data revealed that these differences in sweetness were still significant ($P<0.01$) even when sweetness values were adjusted for the 5 textural parameters measured. Thus the Texturometer did not describe adequately all the textural differences of these gels that affected their apparent sweetness.

Multiple correlation calculations showed that a combination of the 5 textural parameters; hardness, cohesiveness, springiness, chewiness and gumminess, accounted for 52.32% of the variability in sweetness differences. No

single textural parameter alone explained more than 9% of the differences. However, the 3-factor combination of hardness, chewiness and gumminess explained 49.68% of the variation, or almost all of that explained by the 5 parameters combined.

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APPENDIX

Changes Necessary to Adapt Computer Program (Petrasovits and Clark, 1969) to IBM 360 Computer

Main Program

```
      DOUBLE PRECISION SUM,ZNORM,SUM1,SUM2,DET,DLOG
```

Subroutine Input

```
      ICD=5
      IPR=6
```

Subroutine Output

```
      1           TAU(MAXTT,MAXTT),DLOG
```