AN ABSTRACT OF THE THESIS OF

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Title: Influence of Sugar and Acid on Sensory Qualities and Desirability of Blackberry Juice Drink Using Response Surface Methodology.

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Response Surface Methodology (RSM) was used to study the effect of two variables, sugar level (12-16 ^{o}Brix) and acid level (0.3-0.7 % T.A.) on sensory qualities and desirability of blackberry juice drinks. Three blackberry juice levels (10%, 15%, and 20%) were used to study the influence of juice flavor on sensory qualities and desirability of the juice drinks. A trained panel evaluated three attributes, blackberry flavor, sweetness, and sourness intensities, of the juice drinks. The consumer panel gave desirability and three attributes just-right ratings. A Balanced Complete Block Design was used.

Blackberry flavor intensity was enhanced by sugar level. Blackberry flavor intensity was enhanced by acid level to a point about 0.5% T.A., and then decreased. Blackberry flavor intensity was

not related to ^{o}Brix:acid ratio and was only related to the sweetness:sourness ratio at the 20% juice level. Sweetness and sourness intensities increased with increasing sugar and acid levels. There was a suppression effect of sugar and acid on each other in the juice drink. The relationships of sweetness, sourness, and sweetness:sourness ratios to ^{o}Brix:acid ratios were all linear. Desirability rating was related to ^{o}Brix:acid and sweetness:sourness ratios for the 10% and 20% juice levels, for 15% juice level no association was found. The formula which received the closest to "just right" ratings and highest overall desirability rating had in a ^{o}Brix of 15.4 and a % titratable acidity of 0.64, resulting in a ^{o}Brix:acid ratio of 24 and a corresponding sweetness:sourness ratio of slightly less than 1.0. In general, the 15% juice level was the best because of its sugar and acid tolerance and high desirability.

Influence of Sugar and Acid on Sensory Qualities and Desirability of Blackberry Juice Drink Using Response Surface Methodology

by

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INTRODUCTION

Blackberries are a major crop in Oregon. The processed value of the 1986 crop was fourteen million, according to Oregon Agriculture and Fisheries Statistics, 1986-87 (Anonymous, 1986). Blackberry juice is extremely tart and strong-flavored and has a dark purple appearance. Only a small amount of blackberry juice is necessary in a blended drink to provide good blackberry character. Therefore, it was selected as a base for the development of an acceptable juice drink. Sweetness and sourness, in addition to flavor, are major criteria which consumers use in their selection of a juice drink. Achieving the optimum balance of sugar, acid and flavor could aid in the production of a highly desirable blackberry based beverage. In product development, Response Surface Methodology (RSM) is particularly important because it allows for optimization of ingredient levels for specific product characteristics. Besides its importance in optimization techniques, RSM is usually applied to foods which are blends of ingredients to determine and simultaneously solve multivariate equations, which describe the relationship between the variables and the responses to these variables. RSM, therefore, was chosen as a tool to reach the goals in this study.

The objectives of this study are: (a) to prepare drinks at three blackberry juice levels with a range of sweetness and sourness for optimization purposes; (b) to train a panel to rate the intensity of attributes of the blackberry drinks, blackberry flavor, sweetness, and sourness; (c) to train a panel to obtain intensity ratings of the sensory attributes of the drink formulations in the optimization study; (d) to quantify sugar and acid levels and relate them to sweetness and sourness intensity ratings; (e) to relate °Brix:acid ratios to perceived sweetness, sourness, and to the sweetness:sourness ratios; (f) to quantify the relationship between blackberry flavor intensity and sugar and acid levels by RSM; (g) to quantify the relationship among blackberry flavor, sweetness and sourness; (h) to determine the relationship between blackberry flavor intensity and °Brix:acid ratios and sweetness:sourness ratios; (i) with a consumer panel, rate overall desirability on a line scale, and blackberry flavor, sweetness, and sourness on a just-right scale; (j) through the use of RSM, determine the optimum formulation; (k) to determine the relationship between desirability and °Brix:acid ratio and sweetness:sourness ratio; (l) to determine the relationship between just-right and desirability ratings; (m) to determine the relationship between consumer panel desirability ratings and trained panel attribute intensity ratings.

LITERATURE REVIEW

Response Surface Methodology (RSM)

History

The concept of response surface and designs for their exploration began in the chemical industry. The early work was done by statisticians and chemical engineers in the Imperical Chemicals Industries in Great Britain. The first major paper in the field was published by G.E.P. Box (a statistician) and K.B. Wilson (a chemist) in 1951. The authors developed a scientific approach to determining optimum conditions which combined special experimental designs with Taylor First and Second Ordered Equations in a sequential testing procedure called, "Path of Steepest Ascent." Since its introduction in the early 1950's, RSM has become an accepted and widely used set of concepts and techniques. Cochran and Cox (1957), John (1971), Petersen (1985), and Myers (1971) contain explanations of the basic ideas of RSM including both the design of response surface experiments and estimation and interpretation of the fitted surface. Hill and Hunter (1966) summarize the basic principles and present theoretical aspects and practical applications of RSM emphasizing the field of chemistry and chemical engineering. Mead and Pike (1975) review the literature and emphasize the adequacy of RSM application from a biometrics viewpoint.

The Experimental Design of RSM

Agriculture research workers used the experimental designs and equations, researchers in biometrics used the "Path of Steepest Ascent" techniques, while chemists and chemical engineers used both the designs and techniques. There are certain designs that have been chosen frequently by researchers in food product development and research. Mixture designs are reported by Hare (1974), central composite rotatable designs are illustrated by Mullen and Ennis (1979) for up to five variables, and fractional factorial designs are proposed by Henika (1972). Mixture designs are useful for food formulations with more than three ingredients. Central composite rotatable designs (CCRD) have particular characteristics which are a function of several experimental inputs with a minimum number of experimental products, and all the measured responses have equal precision from the center of the experimental region. These characteristics allow the researchers to find optimal conditions easily and efficiently. Examples in the case of two factor applications of CCRD illustrated by Roush *et al.* (1979) provide statistical procedures for fitting a response surface to experimental data, the mathematical process for finding the stationary points, response at the stationary point, and nature of the response surface. A RSM computer program with fractional factorial design was proposed by Henika in 1972. Since then, fractional factorial computer programs have been used by many industrial companies for testing processes and in nutritional experiments with rats and aquatic species (Ely, 1978). Gacula and Singh (1984) present experimental designs and analyses useful in the food and agriculture sciences; Bender *et al.* (1976) present "evolutionary operations", an increasingly popular tool used for the continuous improvement of unit operations using the "slope of steepest ascent".

Application of RSM in Food and Agriculture Science

Numerous research papers in the field of food science contain applications of RSM. In 1967, Kissell used RSM to optimize white layer cake formulations and Swanson *et al.* (1967) used it to develop a technique for sterilizing baby formula. Henika (1972) used RSM twice in 1966, and began to encourage his fellow scientists at Formost Research Center to use RSM. From 1966 to 1971, Henika and colleagues used RSM in 50 different projects which resulted in 300 response surfaces and 1500 contour maps. In 1973, Schroder and Busta employed RSM in studies of bacterial growth while Neilsen *et al.* (1973) used it to study whey protein denaturation. Henselman *et al.* (1974) used the same response surface computer program as Henica described in 1972 in developing high protein bread. Baig and Hoseney (1976) used RSM and stepwise multiple regression in studies of the effects of mixer speed, dough temperature, and water absorption on the mixing time of flours. Aguilera and Kosikouski (1976) used RSM to study the effect of process temperature, feed moisture content and screw speed on soybean extruded products and suggest the methodology can be applied to commercial scale operations. Okaka and Potter (1977) used RSM to study cowpea powder as a replacement of part of the wheat flour in bread making. RSM was chosen by Smith *et al.* (1977) to study stability of emulsifiers and was described as a valuable potential tool for evaluating the composite influence of the numerous variables that affect the properties of food emulsions.

Min and Thomas (1980) used RSM as a statistical method to determine the relationship between ingredients and physical characteristics of dairy whipped topping; and as a tool to optimize the ingredient concentration to produce a satisfactory dairy whipped topping. In 1981, Waszczynskyj *et al.* used RSM optimization techniques to optimize the yield of isolated protein from wheat bran by coupling a enzyme pre-treatment step to regular extraction procedure. Yanaga and Bernhard (1981) used the techniques to optimize the amount of lactose precipitation with manganese (II) chloride and sodium hydroxide for lactose removal from whey. Martin and Tsen (1981) determined by use of RSM the optimum conditions for baking a high-ratio white layer cake by considering the effect of various processing conditions and amounts of ingredients. Cosio *et al.* (1982) determined the optimum temperature and pH for maximum chitinase production for bioconversion of chitin to single-cell protein by using RSM.

Holm and Breedon (1983) measured the optimal shippability of sunflower meal by means of a response surface analysis. Bryer and Walker (1983) composed the effect of sucrose esters upon bread and cookies by a simple RSM design. Whiting (1984) used RSM to study the fat, water exutations and gel strength of frankfurter batters. Nelson and Hsu (1985) used RSM and general regression analysis to isolate and quantitate the factors which effect water absorption and texture of canned navy beans. Vaisey-Genser *et al.* (1987) selected RSM as the approach to determine appropriate ingredient levels of Canola oil, water, and an emulsifying system in cake formulations. Hoo and McLellan (1987) used RSM to model freezing point depression in apple juice concentrate based on a specified range of ^{o}Brix and pectin concentration. Undoubtedly, RSM provides a useful and valuable way to formulate a food product and improve food processing.

Use of RSM in Sensory Evaluation

RSM was first applied to sensory evaluation studies by Pearson *et al.* (1962) for predicting optimum levels of salt and sugar in cured ham. Their dependent variable was taste-panel score, where the flavor of ham was rated on a nine-point hedonic scale. Since then, a number of sensory scientists have reported the use of RSM. Moskowitz (1977) suggested RSM as an optimization procedure in sensory evaluation. Henika (1982) described the application of RSM to sensory data to guide product formulation and to help bridge the gap among sensory evaluation, product development, and marketing. Meyer (1984) pointed out that RSM is useful for optimizing the sensory properties of a new product. Huor *et al.* (1980) used RSM to test acceptability of a fruit punch containing watermelon juice with one or two other juices with the dependent variable being acceptability of fruit punch rated using a nine-point hedonic scale. Schen *et al.* (1980) used RSM to find the optimum conditions for producing a secondary strawberry essence from pomace with intensity and desirability as dependent variables. Bodrero *et al.* (1981) reported that a category scoring system based on the similarities and dissimilarities to meat flavor was developed for evaluation of the contribution of flavor volatiles to the aroma of beef by RSM. McLellan *et al.* (1984) used RSM in sensory analysis of carbonated apple juice produced at various levels of soluble solids and carbonation. Juice samples were evaluated on a non-numeric linear scale using Quantitative Descriptive Analysis (QDA) (Stone and Sidel, 1974). Yamaguichi and Takahasi (1984) used RSM to study the sensory interaction between monosodium glutamate and sodium chloride. Fooladi *et al.* (1986) used RSM for predicting the optimal combinations of meat flavor component. A ten-point scoring system based on similarities and dissimilarities to meat flavor was used.

Taste Qualities in Mixtures

The study of taste interactions is important because most taste stimuli are complex. We rarely taste stimuli comprising one of the four qualities alone. Modern psychophysical studies of taste support the functional independence of the four taste qualities, bitter, sweet, sour, and salty, which were first proposed by Hjalmar Ohrwall (1851-1929) (Bartoshuk, 1977). Based upon this functional independence, different taste qualities do not combine to produce a new taste in taste mixtures, rather the component taste qualities are recognizable in mixtures. Bekesy (1964) reported in his "duplexity theory of taste" that six sensations of the tongue were separated into two groups. Bitter, sweet, and warm seemed to interact among themselves, as did sour, salty, and cold. There was no interaction between the members of the two groups. An interaction (quality fusion), therefore, did not occur with sour and sweet stimuli.

Moskowitz (1970, 1972, 1973, 1974) conducted a series of experiments on mixtures of substances with different tastes as well as mixtures of substances with similar tastes. He hypothesized that the rule which best described the intensity of a mixture was dependent on the qualitative similarity of tastes of its components. He concluded that simple additivity or synergism occurs between pairs of substances with similar qualities while suppression occurs between pairs of substances with different taste qualities. "Additivity" is said to hold when the perceived intensity of the mixture is equal to the sum of the perceived intensities of its components. "Synergism" is said to hold when the intensity of the mixture is perceived to exceed this sum, whereas "suppression" refers to cases in which the intensity of the mixture is perceived to be lower than the summed intensities of the components.

An alternative view of mixture interactions was proposed by Bartoshuk and Cleveland (1977). They reported that the shape of psychophysical functions of the unmixed components predict mixture functions. There are three hypothetical psychophysical functions that relate taste intensity to stimulus concentration: compression, expansion, and addition (Bartoshuk, 1975). A psychophysical function slope of less than one shows compression, a slope greater than one shows expansion, and a slope equal to one shows addition. If the psychophysical functions for the compounds of a two-component mixture are both accelerated, their mixture should exhibit "synergism." If both functions are decelerated, their mixture should show "suppression." The more compression shown by a substance when unmixed, the more that substance will be suppressed when other substances are added to it.

According to recent taste mixture studies by Curtis (1984) using magnitude estimation together with a sip-and-spit procedure, the sugar mixtures showed synergy at low levels and suppression of perceived intensities at higher ones; the acid mixtures showed additivity except at higher concentration where suppression was found. Perceived intensities of mixtures depend on the specific levels of each stimuli and the presentation procedure. Meiselman (1971) demonstrated differences in the power function exponent for saltiness and sweetness using different methods of stimulation. In general, both sourness and sweetness functions showed suppression by flow procedures whereas with a sip and spit procedure, sourness showed suppression (but an increased power function exponent) and sweetness showed expansion.

Sugar-Acid Mixtures in an Aqueous Medium

Several investigations have been conducted on the sugar-acid interrelationship. Fabian and Blum (1943) measured the effect of a subthreshold concentration of one substance upon the perceived intensity of a suprathreshold concentration of another. The sweetness of sucrose was increased by subthreshold concentrations of lactic, malic, citric and tartaric acids and was unchanged by subthreshold concentrations of hydrochloric and acetic acids. The sweetness of fructose was reduced by subthreshold concentrations of all the acids tested except hydrochloric and citric. In addition, the sugars consistently reduced sourness of the acids, though to varying degrees.

Kamen et *al*. (1961) selected a single-stimulus method with a nine-point category scale to rate the intensity of the quality represented by the primary stimulus, ignoring other qualities that might be present. They concluded that suprathreshold levels of citric acid generally increased the sweetness of suprathreshold concentrations of sucrose, whereas sucrose reduced the sourness of citric acid. This conclusion is in agreement with that of Fabian and Blum, but the effect of acids upon sweetness seemed to be in part a function of the specific acids and specific sugars used.

Pangborn (1960) found that sucrose and citric acid at subthreshold, threshold, and suprathreshold levels had a suppressing effect on each other. The same rule applied in diluted fruit nectars, where the greater the acidity the greater the suppression effect on sweetness intensity. Pangborn (1961) repeated the sucrose/citric acid mixture study at suprathreshold concentration using both a single stimulus method and a paired comparison method, where the same general conclusion was observed: citric acid decreased the apparent sweetness of sucrose. This observation, although in agreement with previous work (Pangborn, 1960), disagrees with Fabian and Blum (1943) and Kamen *et al.* (1960), who reported that citric acid increased the sweetness of sucrose.

Moskowitiz (1971) reported the power function exponents for pure tastes and for taste mixtures determined with a sipping procedure. He found that the representative exponents for sweet and salt were 1.3 to 1.5 and for sour and bitter were 1.0 to 1.1. The percentage change in the size of the exponent for sour against a sweet background was unaffected, when sweet against a sour background was reduced 10%. Moskowitz (1972) studied suprathreshold mixtures of citric acid with either glucose or fructose solutions. He stated that the intensity of each taste in the mixture was reduced, which confirms the work by Pangborn which showed suppression in mixtures of different taste qualities.

The Sugar-Acid-Flavor Relationship in a Natural Food

Practical application of taste research often concerns the taste of mixtures of sugars and acids such as in fruit. Sjostrom and Cairncross (1955) state that sugar plays different roles in food flavor: high levels of sweetness have different characteristics from low levels. In processed fruits and confections, sugar, used in quantities of 30% and above, imparts strong sweetness and this becomes a major part of flavor. In beverages at the 10% to 12% level, sugar adds interest and boosts the flavor, while at a seasoning level, 0.2 to 1.5%, sugar may improve the flavor of food without adding conspicuous sweetness. Sivetz (1949) reports that acids play an important role by balancing flavor and sweetness to bring out the flavor of the particular beverage.

Valdes *et al.* (1956a) reported that judges ascribe higher flavor ratings to sweeter samples as well as higher sweetness ratings to solutions with more flavoring (in solutions containing 1.0% organic acids, and various concentrations of sucrose and synthetic raspberry flavorant). The optimum flavor level occurred at about 15% sugar. Studies on apricot, peach, and pear nectars showed that sucrose enhanced fruit flavor up to an optimum sweetness level beyond which it masked flavor; apparent flavor intensity seemed dependent upon the ratio of optimum soluble solids and optimum acidity; and the panel associated preference with the sample they considered most flavorful (Valdes *et al.*, 1956b). Preferred ^{o}Brix:acid ratios for apricot, pear, and peach nectars were 30, 160, and 40 respectively. The ratio for pear nectar is high due to a very low level of acid.

Dryden and Hills (1957) conducted consumer preference studies on applesauce to see how consumer preferences were affected by altering sugar-acid relationships in the given products. The samples were presented in groups in which one of the sugar or acid factors would be held constant while the other was varied by regular increments. However, the higher the acid content of a sauce, the higher was the sugar content required for the optimum desirability. The sauce preferred by most tasters contained about 0.45% acid with a ^{o}Brix value of 22, resulting in a ^{o}Brix:acid ratio of 50.

A consumer survey of canned Bartlett pears by Pangborn and Leonard (1958) showed that pears, of varying acidity canned at five sugar levels, and of ^{o}Brix:acid ratios of between 138 and 171, received the highest scores. Reactions to quality factors the consumer liked and/or disliked showed that the percent response for liking of flavor and sweetness were almost parallel when plotted against ^{o}Brix:acid ratios. The attribute of quality which was most important to the panel and most closely associated with overall preference of canned bartlett pears was flavor. Another consumer survey of canned cling peaches reported by Pangborn *et al.* (1958) showed that the preferred sugar content was 27.6 ^{o}Brix with 0.408% acid among three samples of canned cling peaches varying in sugar content (24.2^{o}, 27.0^{o}, and 27.6 ^{o}Brix) and/or total acidity (0.279%, and 0.408% citric). A consumer survey of lemonade and orangeade by Pangborn *et al.* (1960) found that flavor was the quality factor most frequently given as a reason for selection of samples; sweetness was frequently mentioned and undoubtedly influenced the consumer response. An optimum ^{o}Brix:acid ratio of 16.0 at 11 ^{o}Brix was established for lemonade whereas ^{o}Brix:acid ratio of 18.5 at 13 ^{o}Brix was optimum for orangeade.

In recent years, Ennis *et al.* (1979) conducted a consumer study on fifteen orange beverages in four classes: dry formulations, frozen, canned, and bottled. Analysis of the sensory components influencing preference revealed that sweetness and sourness were the major criteria. For the three frozen orange juice samples, sweetness:sourness ratios ranged from 1.1 to 1.3 with the lowest being the most preferred. The two unsweetened canned juices had ratios of 0.4 and 0.5 while the more preferred sweetened canned juices ratios ranged from 0.5 to 1.2, with the highest being the most preferred. The two bottled juices had ratios of 0.7 and 0.9 with the highest being preferred. The five dry formulations were much sweeter with ratios of 2.4 to 4.1, with the highest ratios (2.6, 3.1, 4.1) being most preferred.

Poll (1981) trained a panel to evaluate eighteen apple varieties for suitability of juice production. He found that the ^{o}Brix:acid ratio, rather than total acid or total sugar content, was very important in determining whether a juice was evaluated as very sour or very sweet. A ^{o}Brix:acid ratio of 15-16 was considered to be the ideal ratio. The panel rated each juice on a sweetness-sourness scale which ranged from -5, extremely sour, to 0, balanced, to +5, very sweet. He conducted a regression analysis of sweetness-sourness data (Y) versus sugar:acid ratio (X) and found the relationship to be defined by the equation $Y = 4.82 + 0.31X$, with $r = 0.91$ ($p < 0.001$).

Board and Woods (1983) investigated the effect of sugar content and acidity on the perceived intensity of flavor and flavor acceptability as judged by consumers for apple juice drinks containing 60% apple juice. Sweetness and sourness increased with increasing levels of soluble solids and acidity respectively. Sourness showed little change with increasing soluble solids and acidity, but soluble solid had a greater influence than acidity on flavor intensity. Sweetness and flavor intensity contributed positively to flavor acceptability, while sourness was a negative factor. For the Granny Smith based juice drinks, the highest acceptability was achieved by drinks having ^{o}Brix:acid ratios of 25 or 30. For the Jonathan based drinks, the highest acceptability was achieved by drinks having ^{o}Brix:acid ratios of 20, 25 or 30.

Fellers *et al.* (1986) conducted consumer testing and physical and chemical analyses on six commercial Florida-packed frozen concentrated orange juice. They found that the flavor improved as the ^{o}Brix:acid ratio increased, and the closer to "just right" was the degree of sweetness, tartness, and bitterness. Consumers judged samples with ^{o}Brix:acid ratios of about 14 to 16 to have the best flavor. The optimum ^{o}Brix:acid ratio for the attribute of sweetness, tartness, and bitterness was about 15 to 16.

Many instances from the above investigations show that in the preparation of fruit juices and of naturally and artificially flavored beverages, maintenance of an optimum ^{o}Brix:acid ratio is important.

METHODS AND MATERIALS

Production of Blackberry Juice Drink

Experimental Design.

Blackberry juice drinks, produced at various levels of sugar and acid, were studied using response surface methodology (RSM) with treatment levels based on a rotatable design (John, 1957). A central composite rotatable design was used for the curvilinear response surface (Myers, 1971).

The independent variables in the experiment were the amounts of acid and sugar in the juice drinks. The amounts of blackberry juice in the drinks were set at 10%, 15%, and 20%, respectively. The dependent variables were attribute intensity responses for the trained panel, and preference responses for the consumer panel. The attributes rated were blackberry flavor, sweetness and sourness.

Each independent variable had five levels. A value of -1.414 was assigned to the lowest level, 0 to the middle level and +1.414 to the highest level. Values between -1.414 and +1.414 for the two factors were determined by calculation according to the central composite rotatable design for two variables (Table 1). The design required thirteen formulations, eight of which were spread throughout the experimental region and five of which were petitions of the formulation located at the middle point (0, 0). The amount of acid in the blackberry juice drink ranged from a low of 0.3% to a high of 0.7%, with a midpoint of 0.5%. The other variable, sugar, ranged from 12^{o} to 16^{o} Brix, with 14^{o} as the midpoint.

It was clear that 13 treatments of each juice level could not be presented to the panel at one time. Therefore, a balanced incomplete block (BIB) design was used. Details are included in the sample presentation section.

Response surfaces were represented mathematically by the second-order polynomials (Henika, 1982).

$$Y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_1 \beta_2 x_1 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \epsilon$$

where x_1 = the concentration of acid, x_2 = the concentration of sugar, ϵ = the random error, and y = the mean of perception for the trained panel, or the mean of desirability for the consumer panel, βs = regression coefficients. The results were analyzed by the usual regression procedures to give estimates of the βs. These estimates are called b values.

Production.

Single strength blackberry juice was prepared by dilution of Marion blackberry concentrate at 68 ^{o}Brix (Kerr Concentrates, Inc., Salem, OR). To make one liter of single strength juice 153 grams of juice concentrate and 10 ml of 100 fold essence were added to one liter of spring water. The reconstituted single strength juice was 10^{o} Brix, in accordance with the FDA standards of identity (The Almanac, 1982) for blackberry juice.

The reconstituted juice had a titratable acidity (T.A.) of 1.26% as anhydrous citric acid, with a pH of 3.20. The single strength juice was diluted with distilled water to levels of 10%, 15%, and 20% v/v juice. For each set of drinks, the acid and sugar levels were prepared according to the experimental design.

The juice drinks were prepared to the desired acidity levels with citric acid monohydrate (U.S.P. grade, J.T. Baker Chemical Co., Phillipsburg, NJ). The final T.A.'s ranged from 0.3% to 0.7% (gms/100 ml as citric acid).

The sugar levels of the juice drinks were prepared to range from 12^{o} to 16^{o} Brix by addition of high fructose corn syrup 55 (Liquidose 77, LSI, Oakland, CA).

The blackberry drinks were placed in 28 oz. bottles, capped, labeled and stored in a $0^{o}C$ cold room overnight for cooling. The products were then stored for three months at $-23^{o}C$ until used for sensory evaluation. Most juices can be frozen without quality changes (Morries, 1944).

Measurement of Chemical and Physical Properties

All chemical/physical properties of the blackberry juice drinks were measured at room temperature, $24-27^{o}C$. pH was measured with a Corning 125 pH meter (Corning Glass Works, Midfield, MA).

Blackberries contain isocitric, malic and traces of other organic acids (Morries, 1944). The titratable acidity was determined by the glass electrode method (AOAC 22.059, 1984), and expressed in terms of anhydrous citric acid percent by volume as total acidity. ^{o}Brix in the juice drink samples, corn syrup, and the juice concentrate were determined with a refractometer (Toko, No. 11250, Laboratory Equipment Co., San Francisco, CA).

Sensory Evaluation of Blackberry Juice Drink

Trained Panel

Panel Training.

Subjects. The panel members, nine graduate students and staff members from the Food Science and Technology Department of Oregon State University, were selected only on the basis of availability and interest in participation. All had previous experience in evaluating taste intensity.

Environment and Duration. Panelists were trained to identify and to scale intensities of three attributes of blackberry juice drink, i.e. blackberry flavor, sweetness and sourness. Training sessions were conducted at a large common table, working independently initially and then sharing individual results and comments in group discussion. This provided an opportunity to re-taste and re-evaluate samples for those who had different response patterns. The panel met for ten sessions over a period of two weeks.

Descriptive Analysis. Descriptive analysis involves the rating of specific attributes defined by the test objective. The subjects were trained to use the line scale (Stone *et al.*, 1974), an unstructured horizontal line 15 cm in length anchored at 0 cm (non-perception) and 15 cm (extreme intensity), for intensity evaluation of each attribute. One distinct advantage of the line scale is the absence of any numerical value associated with the response, plus the limited use of words to minimize word bias (Stone and Sidel, 1985). Panelists were asked to place a vertical mark across the line at that point which best reflected the magnitude of his or her perceived intensity of the corresponding attributes. To make the subject task easier, two samples were used to construct a scale range from low to high for each attribute. These samples are shown in Table 2.

Results. Measuring the distance from the left end of the line to the marked vertical line yielded numerical values of intensity for each attribute.

At the conclusion of the training sessions, all panelists understood the attribute rating method and were consistent in its use.

Sensory Evaluation

Sample Presentation Design. The number of samples that could be effectively evaluated in one session was determined during training sessions. Two sets of four samples were evaluated per sitting. Each set represented one block of four treatments which are described in the following balanced incomplete block (BIB) design:

A BIB design is specified by five parameters: t, k, r, b, λ.

t =	number of treatments
k =	number of experimental units per block
r =	number of replication of each treatment
b =	number of blocks
λ =	number of times each pair of treatments occur in the same block

The BIB design must satisfy the restricting relationships

$\lambda(t-1) = r(k-1)$

$tr = kb = N$

N is the total number of observations in the experiment. Another requirement in the BIB design is that t, k, r, b and λ must be integers. This relationship means that for a given t and k, the required r and b are fixed by the design (Gacula and Singh, 1984; John, 1980). A BIB design with t = 13, k = 4, r = 4, b = 13, λ = 1 was chosen (Plan 11.22, Cochran and Cox, 1950) (Table 3).

Randomization steps were: 1) to assign treatments at random to the numbers in the plan; 2) to randomize the positions of the treatment numbers within each block (the order of the samples within one set for each panelist was randomized).

Serving Procedure. The eight treatments were taken from -23°C storage the day before each testing session and were placed in a 5°C cold room overnight for thawing. Forty-five ml samples were served in 60 ml plastic cups coded with three-digit random numbers.

The samples were served at room temperature (24-27°C). Each panelist received two trays with four samples each. A separate ballot was used for each tray. The presentation order of the two trays were randomized, as well as that of the four samples on each tray. Spring water and unsalted crackers were available for rinsing.

Testing Facility and Testing Techniques. Panelists were seated in individual testing booths with red lights to mask color differences. The ballot is shown in Appendix 1. Panelists were instructed to rinse before tasting and between samples, and to taste one sample at a time going from left to right, evaluating all three attributes before proceeding to the next sample. The panelists were asked to expectorate the samples and to wait thirty seconds between samples.

Data Analysis

Each panelist was presented with the same blocks of the samples for each session. For example, at the first session, all nine panelists evaluated all samples in blocks one and two (Table 3). All panelists completed the whole BIB design. Data on blackberry flavor, sweetness, and sourness were analyzed separately using SAS sixth edition for personal computers (SAS Institute Inc., Cary, NC).

The BIB design was analyzed by analysis of variance. The estimated treatment means were obtained by adding the grand mean to the interblock adjusted treatment effect for each treatment (Gacula and Singh, 1984).

To conduct the RSM procedure, the second-order polynomial on the acid and sugar concentrations was applied to the estimated mean value of each treatment in order to conduct regression analysis (see Equation 1).

The resulting equations were used to calculate the effects of various combinations of HFCS 55 and citric acid levels. Response surface maps and response contour maps were plotted by using an Energraphic program (Enertronics Research, Inc., St. Louis, MO). All points (X_1, X_2) that correspond to a given y were traced by a Pascal program to plot contours of the resulting program. The equation for solving the coordinates are given by Gacula and Singh (1984). The calculations of optimum products are presented by Petersen (1985).

Consumer Panel

Sensory Evaluation.

In order to measure the effect of sweetness and sourness on blackberry juice drink preferences, a consumer panel was organized.

Six sessions, two for each juice level, were conducted in the Sensory Science Laboratory. In each session, 52 panelists were presented different set (block) of four samples in the BIB design (Plan 11.22, Cochran and Cox, 1950) (see Table 3). There were eight repetitions of the BIB design for each juice level, resulting in 32 responses per treatment. Serving procedures and testing conditions were the same as for the trained panel.

When panelists arrived for testing, they were taught how to use the line scale for desirability measurement. They were instructed to taste the four samples in a specified order which was randomized for each panelist. They were also asked to indicate their opinion of the samples for blackberry flavor, sweetness and sourness on a seven-point "just right" scale (-3 = way too low, 0 = just right, 3 = way too high). The ballot is shown in Appendix 2.

Data Analysis.

The BIB design was analyzed by analysis of variance. The estimated treatment means were obtained by adding the grand mean to the treatment effect adjusted for both interblock and intrablock effects, i.e. combined effect (Gacula and Kabula, 1972).

Data were analyzed by using a combination of a BASIC program and a SAS (SAS Institute Inc., Cary, NC) program. The analysis for overall desirability was the same as that described for the trained panel's data analysis. "Just right" scale distributions were drawn on a bar chart by using an Energraphic program.

RESULTS AND DISCUSSION

Introduction of RSM Results

This section describes the results which will be presented and discussed in detail in subsequent sections. The trained panel mean scores and consumer desirability ratings of all juice drinks are shown in Tables 4.1-4.3. The BIB design was used to efficiently collect data and obtain unbiased treatment mean scores. Because of the BIB design, the interblock and/or intrablock effects were used to adjust for differences in evaluations of samples between sessions. The block adjusted treatment means were used to conduct regression analysis. Interblock estimated means were used for the trained panel, while combined block effect means were used for the consumer panel.

The response surface models which resulted from regression analysis of each sensory factor rated are presented in Tables 5.1-5.3. For the model as a whole, R^2, coefficient of determination, was used to explain the percentage of variability accounted for by the equation. The F-ratio values measure the significance of the entire model. To test the adequacy of the quadratic model, lack of fit was computed (Cochran, 1957). A Student's t test of the coefficients was employed to measure the significance of the specific factors in the model. All factors were used whether or not they were significant.

The models were used to sketch response surface (Figures 1, 5, 9, and 15) and contour maps (Fig. 2, 6, 10, and 16) to illustrate the interrelationship between sugar and acid levels and the sensory properties rated by the two panels. An optimum juice drink was calculated for the overall desirability response surface and will be presented in a subsequent section.

Trained Panel Responses

Blackberry Flavor Intensity Response

The R^2 was calculated as 0.767, 0.914, and 0.844 for the 10%, 15%, and 20% juice levels, respectively (Table 5.1-5.3). For data from sensory evaluations, an R^2 of ≥ 0.85 is considered good (Henika, 1982). The F-ratios for model coefficients were significant at $p < 0.05$, $p < 0.01$, and $p < 0.01$ for the 10%, 15%, and 20% juice levels, respectively. Lack of fit was not significant for any of the juice levels indicating adequacy of the models.

The coefficients of first order sugar factors were all positive, however only two, for 15% and 20% juice levels are significant ($p \leq 0.05$). This indicated that an increased sugar level enhanced blackberry flavor perception. The coefficients of first order acid factors were negative for all juice levels, but because they are not significant one can only conclude that acid level had little influence on blackberry flavor perception for these samples.

By inspection of the response surfaces on Fig. 1, one can see that for each juice level, blackberry flavor intensity increased with increasing acid level to a point and then decreased. However, blackberry flavor intensity increased with increasing sugar levels for all juice levels. The contour maps (Fig. 2) showed that the optimum levels of blackberry flavor enhancement by sugar were not within the design of this study. A theoretical maximum was calculated for each blackberry flavor response surface. The maximum response for the 10% juice level was 10.5 at 0.66% T.A. and 20.8^{o}Brix; for the 15% juice level it was 9.98 at 0.28% T.A. and 19.5^{o}Brix; for the 20% juice level it was 9.49 at 0.48% T.A. and 18.1^{o}Brix. The highest values among the samples in the design were all for treatment seven (0.5% T.A., 16^{o}Brix) with values of 9.00, 8.51 and 8.80 for juice levels 10%, 15%, and 20% respectively. Treatment seven was the highest sugar level in the study. These maximum flavor responses suggest that appropriate amounts of sugar can reduce single-strength juice amount usage to produce a rich flavored juice drink.

Because response surfaces are often difficult to interpret, inspection of observed mean scores can be helpful. The effect of acid levels on blackberry flavor intensity at 14^{o}Brix can be observed in Fig. 3a. For the 10% juice level, blackberry flavor intensity steadily increased with acid level, however, for the 15%

and 20% juice levels, blackberry flavor intensity peaked at around the 0.5% acid level and was lower at the 0.7% acid level. The observed values used in Fig. 3a for the 10% juice level were not in agreement with the RSM expected values which also peaked around the 0.5% T.A. level and decreased at the 0.7% T.A. level. The RSM fit was not particularly good for these data as the R^2 was only 0.767. High level of acidity in these juice formulations decreased blackberry flavor intensity.

The effect of sugar level on blackberry flavor intensity at 0.5% T.A. can be observed in Fig. 3b. Blackberry flavor intensity increased with increasing sugar level and was similar across all juice levels. The observed mean ratings across all formulations at the 10%, 15% and 20% juice levels were 7.36, 7.36 and 7.33, respectively. Therefore, for this design, blackberry flavor intensity was the same regardless of how much blackberry juice was in the formulation.

Relationship to °Brix:acid ratio. °Brix:acid ratio were calculated for each formula in the design (Table 6). The °Brix:acid ratio relationship to blackberry flavor intensity was analyzed by using a SAS regression program. The dependent variable was blackberry flavor intensity of observed mean scores and the independent variable was °Brix:acid ratio. There was no linear nor curvilinear relationship between blackberry flavor intensity and °Brix:acid ratio (Fig. 4). Adjusted R^2's were below 0.50

and F ratios of regression models were not significant for all the juice levels.

Sweetness Intensity Response

For sensory response surface of sweetness (Fig. 5), there was no maximum sweetness response in the range of experimental points for any of the three juice levels.

The linear factor coefficients, all of which were significant at $p < 0.01$, were positive for sugar level and negative for acid level. The sweetness model represented a positive effect of sugar and a negative effect of acid on sweetness perception.

The coefficient of determination, R^2, were calculated as 0.964, 0.936 and 0.915 for the 10%, 15% and 20% juice levels, respectively (Table 5.1-5.3). The F-ratios were significant at $p < 0.001$, $p < 0.001$, and $p < 0.01$ for the 10%, 15%, and 20% juice levels, respectively.

The highly sloped contour lines on Fig. 6 further support the evidence that increased sugar level caused an increase in sweetness perception.

The effect of acid level on sweetness at 14 °Brix can be observed in Fig. 7a. Acid level has an extreme depressing effect on sweetness perception and the effect was similar across all juice levels.

The effect of sugar level on sweetness at 0.5% T.A. can be observed in Fig. 7b. Sweetness intensity increased with increasing sugar level but the slopes of the lines appeared different at all juice levels. At the 15% level, the slope appeared to be lower than that of the 10% and 20% lines, indicating that sweetness intensity at this flavor level was not as affected by sugar level.

Relationship to °Brix:acid ratio. The relationship between °Brix:acid ratio and sweetness was analyzed using SAS regression analysis. The dependent variable was observed mean scores of sweetness and the independent variable was °Brix:acid ratio. The regression models relating °Brix:acid ratios to sweetness for each juice level are summarized in Table 7 and the ratings are plotted in Fig. 8.

The F-ratios were significant of $p < 0.01$, $p < 0.001$, and $p < 0.05$ for the 10%, 15%, and 20% juice levels, respectively. The adjusted R-squares were calculated at 0.736, 0.808, and 0.567 for the 10%, 15%, and 20% juice level drinks, respectively. The first order coefficients of °Brix:acid ratio were all positive and significant for all the juice levels. Sweetness increased with increasing °Brix:acid ratio with an average slope of 0.78 (0.736 to 0.846).

Sourness Intensity Response

The coefficient of determination, R^2, of the three juice levels were 0.946, 0.944 and 0.912, respectively (Table 5.1-5.3). The F-ratios were all significant at $p < 0.001$. Lack of fit of the quadratic model was significant at the 15% juice level model, however the quadratic model did fit both the 10% and 20% juice level drinks. The linear model was adequate for the 15% juice level drink ($p \leq 0.01$).

The acid factor in the model was highly significant ($p \leq 0.001$) at all three juice levels, however the sugar factor was significant ($p \leq 0.05$) only at the 10% juice level. The shapes of the response surfaces for sourness were very different across the three juice levels (Fig. 9). For example, the 10% juice level plots (Fig. 9a and Fig. 10a), resulted from significant linear, quadratic and interaction effects in the model (Table 5.1). Only the 10% juice level model had a significant sugar and acid interaction, indicating that sourness response depended on both the added sugar and acid. This can be readily observed in Fig. 10a. The sourness response of the 15% juice drink increased with an increasing acid level with the effect of sugar being relatively constant (Fig. 9a and Fig. 10b). The response surface of the 20% juice drink (Fig. 9c) was more complex. Sugar enhanced sourness perception at low acid levels, while it reduced sourness perception at high acid levels.

The above data suggests that blackberry juice level had a strong influence on sourness perception. For example, at the 10% blackberry juice level, low sugar level enhanced sourness perception. This phenomenon did not occur at higher blackberry juice levels.

The effect of acid level on sourness at 14^{o}Brix can be observed in Fig. 11a. Sourness intensity increased with increasing acid levels for all the juice drinks.

The effect of sugar level on sourness at 0.5% T.A. can be observed in Fig. 11b. For the 10% and 20% juice levels, the sugar level has a depressing effect on sourness perception. For the 15% juice drink, the sugar level had little enhancing effect on sourness perception.

Relationship to ^{o}Brix:acid ratio. The relationship between ^{o}Brix:acid ratio and sourness in log-log coordinates was analyzed by using a SAS regression program. The regression statistics and coefficients were summarized in Table 7 and plotted in Fig. 12.

The F-ratios were significant at $p < 0.01$, $p < 0.001$, and $p < 0.01$ for the 10%, 15%, and 20% juice levels, respectively. The first order coefficients of ^{o}Brix:acid ratios were all negative and significant for all the juice levels. The sourness decreased with increasing ^{o}Brix:acid ratio with an average slope of -1.18 (-0.976 to -1.328).

^{o}Brix:acid Ratio Relationship to Sweetness:Sourness Ratio

The relationship of ^{o}Brix:acid ratios to sweetness:sourness ratios were analyzed using the SAS regression program. The F ratios and slopes were highly significant of $p < 0.001$ for all juice levels (Table 7). The adjusted R^2's were calculated as 0.930, 0.940, and 0.912 for the 10%, 15%, and 20% juice levels, respectively. This indicates that there is a positive linear relationship of °Brix:acid ratio with sweetness:sourness ratio. This relationship can be seen in Fig. 13. The sweetness:sourness ratio increased with increasing °Brix:acid ratio with an average slope of 1.9 (1.813 to 2.065). Because the slope is so high, a small increase in the sugar acid ratio results in a larger increase in the sweetness:sourness ratio. This linear relationship model can be used to predict the amount of sugar and/or acid needed in the production of a specific sweetness:sourness level in a formulated drink.

Blackberry Flavor Intensity Relationship to Sweetness:Sourness Ratio

The sweetness:sourness ratios (Table 6) and blackberry flavor observed mean intensity values (Tables 4.1-4.3) were analyzed by using a SAS regression program. There was no significant relationship between sweetness:sourness ratios and blackberry flavor intensity ratings at the 10% and 15% juice levels (Fig. 14). For the 20% juice level, however, the F ratio and slope were significant at $p < 0.05$ for the curvilinear model with an R^2 of 0.509 (Table 8.1). The maximum blackberry flavor intensity was located at a sweetness:sourness ratio of approximately 1.65 (Fig. 14). Therefore, when the formulations were high in sweetness (above a ratio of 1.65) as compared to sourness, blackberry flavor was suppressed.

Consumer Panel

Desirability Response

The coefficient of determination, R^2, of the models for the three juice levels were 0.913, 0.939 and 0.495, for the 10%, 15% and 20% juice levels, respectively (Tables 5.1-5.3). The F-ratios were significant at $p < 0.01$ for the 10% and 15% juice levels, but were not significant at the 20% juice level. Lack of fit was not significant, indicating the adequacy of the model.

The desirability response surface (Fig. 15a) and contour map (Fig. 16a) for the 10% juice level illustrated that there was an optimum sugar-acid level. The maximum desirability at the 10% juice level was calculated as 9.4 which occurred at a combination of 0.56% T.A. and 14.2°Brix. The °Brix:acid ratio at this optimum formula was 25.4. This theoretical optimum formula was similar to the midpoint formula in the design (0.5% T.A. and 14°Brix), which had a °Brix:acid ratio of 28 (Table 6) and desirability ratings of 8.92 to 9.56 (Table 4.1), the highest in the design.

A theoretical maximum desirability level, 10.9, occurred at 0.56% T.A. and 20.4°Brix in the 15% juice level model. The optimum °Brix:acid ratio was 36.4 but the sugar level of 20.4° Brix was beyond the experimental points. This indicates that more sugar was needed for optimum desirability in the 15% juice level. The response surface is shown in Fig. 15a and the contour map in Fig. 16b.

The response surface of the 20% juice level (Fig. 15c) was saddle shaped, with maxima and minima encountered at various combinations of sugar and acid. There was a saddle point (Fig. 16c), $y^o = 8.7$, at 0.48% T.A. and 12.2°Brix. This means that the most desirable sample occurred at 0.48% T.A. or below and at 12.2°Brix or above. Therefore, the optimum juice drink with a 20% juice level should contain more than 12.2°Brix sugar but an acid level not to exceed 0.48% T.A. These RSM results do not relate well to the observed desirability scores where the samples receiving the highest ratings were all higher in acid than 0.48. This was probably due to the poor fit of the model to the data (Table 5.3).

The effect of acid level on desirability ratings at 14°Brix can be observed in Fig. 17a. There is a peak in desirability ratings at around 0.5% T.A. for each juice level. Scores were different among the three juice levels. The desirability ratings of the 15% juice level were higher than for the 10% and 20% juice levels. It may be because the 15% juice drink, in general, was more balanced in blackberry flavor, sweetness and sourness, especially at the lowest acid level. Both the 10% and the 20% juice level drinks received low desirability scores at the low acid level. Perhaps the 10% juice level was too low in overall flavor impact at the low acid level, while the 20% juice level drink was out of balance, e.g. it did not have enough sourness to balance the blackberry intensity.

The effect of sugar level on desirability ratings at 0.5% T.A. can be observed in Fig. 17b. For the 10% juice drink, there was a peak at around 14°Brix. This agrees with the response surface data discussed earlier where the maximum desirability was at 0.56% T.A. and 14.2°Brix. For the 15% and 20% juice drinks, the desirability ratings did not peak and continued to increase above the 14°Brix level indicating the drinks were not sweet enough. At higher blackberry juice levels more sugar is needed to achieve an optimum score.

Relationship to °Brix:acid ratio. The relationship between °Brix:acid ratio and desirability ratings was analyzed by using a SAS regression program (Table 8.1-8.2). The plot is shown in Fig. 18. For the 10% juice level, there was a significant linear ($p < 0.05$) and curvilinear ($p < 0.05$) relationship, however the curvilinear relationship was stronger ($R^2 = 0.691$). For the 15% juice level, neither relationship was significant. At the 20% juice level, there was a significant ($p < 0.05$) curvilinear relationship ($R^2 = 0.506$). Both curvilinear regression models do not fit very well, however, a curvilinear relationship of °Brix:acid ratio to desirability rating is evident in Fig. 18a and 18c. The optimum desirability was located at a °Brix:acid ratio of approximately 25 for the 10% juice and 30 for the 20% juice.

Just Right Ratings

The purpose of using just right scales in consumer testing was to see how their results related to RSM from trained panel testing.

Percentage distributions generated from just right scale ratings of blackberry flavor, sweetness, and sourness for each formula tested are shown in Figures 19 through 27. The acid level effect on blackberry flavor, sweetness, and sourness are summarized in Tables 9.1, 9.2, and 9.3, respectively by three groups. The first sugar level group includes formulas 1, 8, and 3 where sugar level is low and acid levels are low, medium and high, respectively. The second sugar level group includes formulas 6, 9, and 5 where sugar level is medium, and the third sugar level group included formulas 2, 7, and 4, where sugar level is high, both groups having corresponding acid levels of low, medium, and high, respectively. The sugar level effect on blackberry flavor, sweetness, and sourness also can be observed in Tables 9.1, 9.2, and 9.3, respectively by grouping the formulas by acid level. The first acid level group includes formulas 1, 6, and 2 where acid level is low. The second acid level group includes formulas 8, 9, and 7 where acid level is medium. The third acid level group includes formulas 3, 5, and 4 where acid level is high. The formulas in each group were at low, medium, and high sugar levels, respectively.

Blackberry Flavor

Effect of acid. When the sugar level was held constant, and acid level was increased, in general, just right scale ratings changed from too weak (low acid levels) to just right (higher acid levels) (Table 9.1). These data suggest that blackberry flavor was enhanced by increasing acid levels. An exception to this occurred at the 10% juice level at the low sugar level, where all acid levels were rated too weak. Formula 4 had blackberry flavor ratings closer to just right then did formula 7 because of formula 4's higher acid level. Inspection of trained panel observed mean scores (Table 9.1), group by group, indicate there was an optimum acid level for blackberry flavor intensity for all the juice levels. Blackberry flavor intensity peaked around the medium acid level (0.5% T.A.) and at the high sugar level for all the juice levels (formula 7). This phenomenon was predicted by the RSM model correctly, but it was not in agreement with the just right scale ratings from the consumer panel study where formula 4 received the closest to "just right" ratings.

Effect of sugar. When acid level was held constant, and sugar level was increased, in general, just right scale ratings changed from too weak (low sugar) to just right (higher sugar levels). An exception occurred at the low acid level where only at the higher juice levels and highest sugar levels did ratings approach just right. This finding is generally consistent with trained panel results. Inspection of observed mean scores (Table 9.1) group by group indicate that the higher the sugar level the higher the blackberry flavor intensity ratings for all the juice levels.

Based on the data discussed above, increasing amounts of sugar and acid had similar effects on just right ratings of blackberry flavor. The just right ratings of blackberry flavor for the 10% juice level drinks were often rated as too weak, whereas the 15% and 20% juice levels drinks were both rated similarly, usually closer to just right. According to the trained panel study and RSM prediction, the effect of increased acid on blackberry flavor intensity was also influenced by juice level. The effect of increased sugar on blackberry flavor intensity was the same regardless of juice level for both consumer panel and trained panel results.

The formulas which received ratings closest to just right occur at the highest acid and sugar levels, represented by formula 4 (Table 9.1). The corresponding trained panel blackberry flavor intensity ratings ranged from 7.86 - 8.00. Higher trained panel intensity ratings occurred in formulas 2 and 7, where acid levels were lower, yet the consumer panel felt the blackberry flavor was slightly too low. This reinforces the fact that the consumer panel's ratings of blackberry flavor in formula 4 was influenced by the high acid content. Formula 4 has a ^{o}Brix:acid ratio of approximately 24 (Table 6). The ^{o}Brix:acid ratio corresponds to a trained panel sweetness:sourness ratio of around 0.90.

Sweetness

Effect of acid. When sugar level was held constant, and acid level was increased, in general, just right scale ratings changed from too sweet to just right to not sweet enough, peaking at the medium acid level. An exception occurred at the highest sugar level where the highest acid level was needed to achieve a just right rating for the 10% and 15% juice levels.

Effect of sugar. When the acid level was held constant, and the sugar level was increased, the response was specific for each acid level. At the low acid level, both medium and high levels of sugar were rated as "too sweet," while the low sugar level received a mixture of responses with large portions of the population rating the sweetness as "too much" and "not enough." At the medium acid level, almost all sugar levels and juice levels were rated as "just right." At the high acid level, formulas with low and medium amounts of sugar were rated as too weak or received mixed ratings, while the highest sugar level (formula 4) was rated closest to "just right."

Based on the results discussed above, sweetness was suppressed with increasing acid and enhanced with increasing sugar for all the juice levels. This finding is consistent with trained panel ratings by inspection of observed mean scores (Table 9.2) group by group. The sweetness response surfaces from RSM predictions also reflect the same phenomenon.

Formulas 4, 8, and 9 received the closest to just right ratings in sweetness, and they had ^{o}Brix:acid ratios of 24, 24, and 28, respectively. These ^{o}Brix:acid ratios correspond to trained panel sweetness:sourness ratios of around 0.90, 0.68, and 0.97, respectively.

Sourness

Effect of acid. When sugar level was held constant, and acid level was increased, in general, just right scale ratings changed from not sour enough to just right to too sour, peaking at the medium acid level (Table 9.3). An exception occurred for the low acid samples at the 15% juice level where all the ratings were close to just right. Also, at the high acid and low sugar level, the 15% juice sample results were bimodally distributed. The 15% juice level drinks apparently had more acid tolerance than the other two juice levels. Another exception occurred at the highest acid and sugar level (formula 3) where all samples received just right ratings. Evidently the high acid was balanced by the high sugar level in this drink.

Effect of sugar. When the acid level was held constant, and sugar level increased, the response was specific for each acid level (Table 9.3). At the low acid level, all the sugar levels were rated not sour enough. At the medium acid level, all sugar levels were rated as just right. At the high acid level, both low and medium levels of sugar were rated as too sour, while the high sugar level was rated as just right.

Relating trained panel observed mean scores to just right ratings (Table 9.3), formulas 4, 7, 8, and 9 received the closest to "just right" ratings in sourness with ^{o}Brix:acid ratios of approximately 24, 24, 28, and 32, respectively (Table 6). These ^{o}Brix:acid ratios correspond to trained panel sweetness:sourness ratios of 0.90, 1.4, 0.68, and 0.97, respectively.

Just Right Distributions Relationship to Desirability

The desirability ratings for each juice level can be observed in Table 6. For the 10% juice level, formulas 4, 7, 8, and 9 received the highest desirability ratings of 8.81, 8.65, 8.83, and 9.22, respectively. For the 15% juice level, formulas 2, 4, 5, 7, and 9 received even higher desirability ratings of 9.73, 9.33, 9.27, 9.42, and 9.34, respectively. For the 20% juice level, formulas 4, 7, and 9 received the highest desirability ratings of 9.39, 9.29, and 9.13, respectively. Based on the above data, the consumer panel appeared to like the 15% and 20% juice level samples better than the 10% juice level samples. The just right scale ratings were used to evaluate these data. The 15% and 20% juice levels had ratings closer to just right in blackberry flavor than did the 10% juice level (Table 9.1). The 15% juice level had more sugar and acid tolerance than the other two juice levels as shown in Table 9.2-9.3 and discussed previously.

For all the juice levels, formulas 4, 7, and 9 had the highest desirability ratings with ^{o}Brix:acid ratios of 24, 32, and 28, respectively. Their just right ratings were located at "just right" for every attribute.

These results are in agreement with the ^{o}Brix:acid versus desirability results presented earlier where optimum desirability for the 10% and 20% juice levels were found to be at a ^{o}Brix:acid ratio of 25 and 30, respectively.

Integration of Trained Panel and Consumer Panel Data

Trained panel data represents the actual qualities and their intensities in the various drinks while consumer data represents how much the formulas are liked, and why (as inferred by just right scale ratings). The integration of the two types of sensory data will aid in the definition of the relationship between a product's sensory profile and its desirability.

Desirability Relationship to Sweetness:Sourness Ratio

The sweetness:sourness ratio and desirability values were analyzed by using the SAS regression program for both linear and curvilinear regression models. Regression analysis revealed no significant association between desirability ratings and sweetness:sourness ratios at the 15% juice levels (Table 8.1). For the 10% juice level there was a significant ($p < 0.05$) linear relationship with $R^2 = 0.516$ (Fig. 28). Desirability ratings decreased with increasing sweetness:sourness ratio with a slope of -0.786 (Table 8.1). The R^2 was quite low, suggesting a poor fit (Table 8.1). For the 20% juice level, the F ratio for the curvilinear model was significant at $p < 0.01$ with adjusted R^2 of 0.731 (Table 8.2). The maximum desirability for the 20% juice level was located at a sweetness:sourness ratio of approximately 1.4 (Fig. 28).

Just Right Distribution Relationship to Sweetness:Sourness Ratios

The formulas rated as "just right" by the consumer panel were formula 4 for blackberry flavor, formulas 4, 8, and 9 for sweetness and formulas 4, 7, 8, and 9 for sourness (Table 9.1-9.3). Formulas 4 and 8 had sweetness:sourness ratios of less than 1.00 for each juice level. Formula 9 had sweetness:sourness ratios of 0.94, 0.93 and 1.05 for the 10%, 15%, and 20% juice levels, respectively. Formula 7, which was rated just right only for sourness, had sweetness:sourness ratios of greater than 1.00. It was rated as being too sweet and too low in blackberry flavor. Formula 4, the only sample rated as just right for all three attributes, had a °Brix:acid ratio of 24 and a sweetness:sourness ratio of 0.85 to 0.94 (Table 6).

Summary of Results

Blackberry Flavor Intensity. Sugar level had a strong influence while acid and blackberry juice levels had a very small influence on perception of blackberry flavor intensity. Blackberry flavor intensity increased with increasing sugar level. Blackberry flavor intensity increased with increasing acid level to a point, about 0.5% T.A., and then decreased. This is supported by the fact that the theoretical maximum blackberry flavor intensity responses was within a narrow range of °Brix, 18.1 to 20.8, but within wide ranges of titratable acidity, 0.28 to 0.66%, and blackberry juice level, 10% to 20%. Blackberry flavor intensity was not related to °Brix:acid ratios and was only related to the sweetness:sourness ratio at the 20% juice level.

Sweetness. Sugar level positively affected sweetness perception, while acid level negatively affected sweetness perception. Sweetness perception increased with increasing °Brix:acid ratio with an average slope of 0.78.

Sourness. Acid level strongly influenced sourness perception, while the sugar level effect varied depending on blackberry juice level. At the 15% juice level, sugar had little influence on sourness perception. At the 10% and 20% juice levels, complex responses were observed, but in general sourness was somewhat depressed by increasing sugar level. Sourness perception decreased with increasing ^{o}Brix:acid ratio with an average slope of -1.18.

^{o}Brix:Acid Ratio vs. Sweetness:Sourness Ratio. There was a positive linear relationship between the ^{o}Brix:acid ratio and sweetness:sourness ratio. The high slope of 1.9 suggests that a small increase in the ^{o}Brix:acid ratio results in a larger increase in the sweetness:sourness ratio.

Consumer Panel Desirability. Based on the RSM analysis, an optimum desirability was achieved at the 10% juice level, for a theoretical sample composed of 14.2 ^{o}Brix and 0.56% T.A. and having a ^{o}Brix:acid ratio of 25.4. The 15% juice level's theoretical optimum for acid was also 0.56% T.A., however for sugar it was beyond the experimental points in the study at 20.4 ^{o}Brix. The relationship for the 20% juice level was described by a saddle point such that the optimum drink could be more than 12.2 ^{o}Brix but not exceeding 0.48% T.A. Therefore, optimum desirability at all juice levels was approximately 0.5% T.A. and was above approximately 12.2 °Brix, or a °Brix:acid ratio of above 24. There was a significant curvilinear relationship between desirability and °Brix:acid ratios for the 10% and 20% juice levels with optima at °Brix:acid ratios of approximately 25 and 30, respectively. For the formulas tested, formulas 4, 7, and 9 received the highest desirability ratings, at 9.18, 9.12 and 9.23, respectively.

Relationship of Desirability to the Sweetness:Sourness Ratio. Juice level was the determining factor for the shape of the relationship between desirability and the sweetness:sourness ratio. For the 10% juice level desirability decreased with an increasing sweetness:sourness ratio. No association was found at the 15% juice level. For the 20% juice level, a maximum sweetness: sourness ratio of 1.4 was found.

Consumer Just Right Ratings. For blackberry flavor, formula 4 had the closest to "just right" ratings with a °Brix:acid ratio of 24 and a sweetness:sourness ratio of 0.9; for sweetness, formulas 4, 8, and 9, had the closest to "just right" ratings with °Brix:acid ratios of 24-28 and sweetness:sourness ratios of 0.68-0.97; for sourness, formulas 4, 7, 8, and 9, had the closest to "just right" ratings with °Brix:acid ratios of 24-32 and sweetness:sourness ratios of 0.68-1.4. Formula 4, the only formula rated as "just right" for all three attributes, had ^{o}Brix:acid ratio of 24 and a sweetness:sourness ratio of 0.85-0.94.

Discussion

The trained panelist's response to changes in ^{o}Brix and % titratable acidity was predictable. Thus sugar level had a positive effect on blackberry flavor and sweetness perceptions, and a negative effect on sourness perception. Acid level had a positive effect on blackberry flavor and sweetness perceptions. For fruit flavor intensity, the results were in agreement with Board and Woods (1983) where apple flavor intensity increased with increasing ^{o}Brix and with decreasing acid level. For sweetness and sourness intensities, the results were in agreement with Pangborn (1960, 1961) and Moskowitz (1971, 1972) where suppression of sweetness and sourness occurred in sugar-acid mixtures in an aqueous medium.

There was a significant positive linear relationship between sweetness intensity and ^{o}Brix:acid ratio, and there was a significant negative linear relationship between sourness intensity and ^{o}Brix:acid ratio (X) and the sweetness:sourness ratio (y). This relationship ($y = -2.83\ x^{1.9}$) defines how adjustments in sugar and acid levels effect perceived differences. This was in general agreement with Poll (1981) where a positive linear relationship of ^{o}Brix:acid ratio (x) and sweetness-sourness data

(y) was found, however with a slope of only 0.31. This slope was very low due to the use of a "balance" scale, rather than an intensity scale.

Blackberry flavor intensity was not related to ^{o}Brix:acid ratios and was only related to the sweetness:sourness ratio at the 20% juice level. Because the effect of sweetness on blackberry flavor intensity was a positive linear relationship and because the effect of sourness on blackberry flavor intensity was a curvilinear relationship, the relationship between blackberry flavor intensity and sweetness:sourness ratio was expected to be curvilinear. This was the case only for the 20% juice level, but the relationship was not strong enough for the 10% and 15% juice levels to be significant. Due to the highly significant linear relationship between ^{o}Brix:acid ratio and sweetness:sourness ratio one might expect there should be a curvilinear relationship between blackberry flavor intensity and ^{o}Brix:acid ratio. This was not the case in study. It is important to remember that the RSM study was designed to evaluate the ^{o}Brix-% titratable acidity relationship, not those of ^{o}Brix:acid ratio or the sweetness:sourness ratio.

Based on RSM desirability analysis, an optimum desirability at all juice levels was at a ^{o}Brix:acid ratio of 24 and above. There was a significant curvilinear relationship between desirability and ^{o}Brix:acid ratio for the 10% and 20% juice levels, and between desirability and sweetness:sourness ratio for the 20% juice level. The reason for all juice levels not having the curvilinear relationship may be due to the fact that the RSM study was not designed to evaluate the ^{o}Brix:acid ratio or the sweetness:sourness ratio. There are other researchers who reported similar findings in other juice base studies. Fellers *et al.* (1986) reported that flavor ratings (nine-point hedonic scale) improved as ^{o}Brix:acid ratio increased from 13.14 to 17.00 in commercial Florida-packed frozen concentrated orange juices. Dryden and Hill (1957) found an optimum ^{o}Brix:acid ratio of 50 in their study on applesauce. Pangborn (1960) tested lemonade and orangeade and found optimum ^{o}Brix:acid ratios of 16-18.5. Board and Woods (1983) tested apple juice drink and reported that optimum ^{o}Brix:acid ratios for different apple varieties ranged from 20-30. Calculated sweetness:sourness ratios from work by Ennis *et al.* (1979) ranged from a low of 0.4 for unsweetened canned juices to a higher of 4.1 for dry formulations in an orange beverage system. The sweetness:sourness ratios from the current study ranged from 0.42 to 3.02 with an optimum at slightly less than 1.0, well within the values calculated from data presented by Ennis *et al.* (1979).

Blackberry juice level had no influence on blackberry flavor intensity but it did influence sweetness and sourness intensity ratings from the trained panel. Therefore, adjustment of blackberry flavor level, through its effect on sweetness and sourness perceptions, can influence desirability. In general, the

10% juice level had lower desirability ratings than the 15% and 20% juice levels and the flavor intensity appeared equivalent across all juice levels. Comparing the results from three juice levels suggests that the 15% juice level was the best because of its sugar and acid tolerance, and high desirability ratings.

CONCLUSIONS

1. The relationships of sugar and acid levels to sweetness and sourness ratings were linear.

2. The relationships of sweetness, sourness and the sweetness:sourness ratio to the ^{o}Brix:acid ratio were all linear.

3. Blackberry flavor was enhanced by increased sugar level. Blackberry flavor intensity was enhanced by increased acid level to a point, and then flavor intensity decreased.

4. Blackberry flavor intensity was not related to ^{o}Brix:acid ratios and was only related to the sweetness:sourness ratio at the 20% juice level.

5. It was not possible to clearly define an optimum formulation for all the juice levels. The formula which received the closest to "just right" ratings and the highest overall desirability ratings, formula 4, had a ^{o}Brix of 15.4, a % titratable acidity of 0.64%, resulting in a ^{o}Brix:acid ratio of 24.

6. There was a significant curvilinear relationship between desirability and ^{o}Brix:acid ratios for the 10% and 20% juice levels with optima at ^{o}Brix:acid ratios of approximately 25 and 30, respectively. For the 15% level no association was found.

7. For the 10% juice level, desirability decreased with an increasing sweetness:sourness ratio. For the 20% level, a maximum sweetness:sourness ratio of 1.4 occurred. For the 15% level no association was found.

8. By use of the just right scale, it was possible to determine how desirability ratings were influenced.

9. Desirability ratings were related to sweetness:sourness ratios for the 10% and 20% juice levels, however, each juice level was affected differently. For the 10% level there was a significant linear relationship with a slope of -0.786. For the 20% juice level, there was a significant curvilinear relationship with a maximum sweetness:sourness ratio of 1.4. For the 15% level no association was found.

Table 1. Experimental blackberry juice drink ^{o}Brix and titratable acidities in the central composite design for response surface analysis. A total of 13 combinations for each juice level. Drinks were prepared at 10%, 15%, and 20% juice.

	LEVEL OF ACID		LEVEL OF SUGAR	
Formula*	Coded	Titratable Acidity as % citric acid	Coded	^{o}Brix
1	-1	0.36	-1	12.6
2	-1	0.36	1	15.4
3	1	0.64	-1	12.6
4	1	0.64	1	15.4
5	1.414	0.7	0	14
6	-1.414	0.3	0	14
7	0	0.5	1.414	16
8	0	0.5	-1.414	12
9	0	0.5	0	14
10	0	0.5	0	14
11	0	0.5	0	14
12	0	0.5	0	14
13	0	0.5	0	14

* Formula 1 to Formula 4 were four, 2-by-2 factorial points; Formula 5 to Formula 8 were four axial points; Formula 9 to Formula 13 were five repetitions at midpoint on central composite rotatable design.

Table 2. The samples used to construct a scale range from low to high for each attribute.

BLACKBERRY FLAVOR		SWEETNESS		SOURNESS	
INTENSITY	FORMULA	INTENSITY	FORMULA	INTENSITY	FORMULA
LOW	10% juice 0.5% T.A. 14^{o}Brix	LOW	10% juice 0.5% T.A. 12^{o}Brix	LOW	10% juice 0.3% T.A. 14^{o}Brix
HIGH	20% juice 0.5% T.A. 14^{o}Brix	HIGH	10% juice 0.5% T.A. 16^{o}Brix	HIGH	10% juice 0.7% T.A. 14^{o}Brix

Table 3. Testing plan based on balanced incomplete block design[a].

BLOCK	TREATMENTS			
(1)	1	2	4	10
(2)	2	3	5	11
(3)	3	4	6	12
(4)	4	5	7	13
(5)	5	6	8	1
(6)	6	7	9	2
(7)	7	8	10	3
(8)	8	9	11	4
(9)	9	10	12	5
(10)	10	11	13	6
(11)	11	12	1	7
(12)	12	13	2	8
(13)	13	1	3	9

[a] Cochran and Cox, 1950, p. 333

Table 4.1. Mean scores of 10% blackberry juice level drinks for thirteen treatments.

FORMULA NUMBER[e]	MEAN FLAVOR INTENSITY SCORE			MEAN SWEETNESS SCORE			MEAN SOURNESS SCORE			MEAN OVERALL DESIRABILITY SCORE		
	Observed[a] Means	Adjusted[c] Means	RSM[d] Expected	Observed Means	Adjusted Means	RSM Expected	Observed[b] Means	Adjusted Means	RSM Expected	Observed[b]	Combined[e] Estimated	RSM Expected
1	6.80	6.714	6.340	7.07	6.838	7.216	3.99	3.040	3.205	7.43	7.114	7.432
2	8.01	8.163	7.932	9.89	10.468	10.620	5.41	5.288	4.433	6.99	6.989	7.275
3	5.89	4.912	5.557	4.50	3.995	4.034	10.57	11.525	12.012	8.43	8.587	8.561
4	8.00	7.590	8.405	7.37	7.781	7.594	8.19	7.912	7.379	8.81	8.891	8.832
5	7.79	7.406	6.460	5.55	5.167	5.311	9.96	10.535	10.492	8.16	8.368	8.482
6	6.85	6.147	6.679	9.44	10.036	9.700	3.13	1.771	2.183	6.84	6.956	6.582
7	9.00	9.445	9.118	9.36	9.625	9.689	5.73	5.068	5.974	8.65	8.666	8.559
8	6.18	6.065	5.978	5.83	5.021	4.765	8.56	8.918	8.381	8.83	8.632	8.479
9	6.61	6.898	7.840	6.65	6.636	7.185	8.31	8.716	7.985	9.11	8.805	9.210
10	7.87	8.541	7.840	7.75	7.884	7.185	7.24	7.621	7.985	8.99	9.212	9.210
11	7.38	7.853	7.840	7.24	7.197	7.185	6.96	7.031	7.985	9.56	9.199	9.210
12	7.51	7.903	7.840	6.54	6.644	7.185	8.40	8.906	7.985	8.92	9.122	9.210
13	7.75	8.002	7.840	7.67	7.562	7.185	7.54	7.652	7.985	9.54	9.710	9.210

[a] Observed mean: Average of 36 results for trained panel.
[b] Observed mean: Average of 32 results for consumer panel.
[c] Estimated mean: Observed mean + block estimated effect according to BIB design.
[d] Expected mean: Calculated from response model.
[e] Formulas described in Table 1.

Table 4.2. Mean scores of 15% blackberry juice level drinks for thirteen treatments.

	MEAN FLAVOR INTENSITY SCORE			MEAN SWEETNESS SCORE			MEAN SOURNESS SCORE			MEAN OVERALL DESIRABILITY SCORE		
FORMULA NUMBER[e]	Observed[a] Means	Adjusted[c] Means	RSM[d] Expected	Observed Means	Adjusted Means	RSM Expected	Observed[b] Means	Adjusted Means	RSM Expected	Observed[b]	Combined[e] Estimated	RSM Expected
1	6.09	5.779	5.758	7.01	6.637	7.354	6.22	6.176	5.378	8.60	8.340	8.213
2	8.34	9.115	8.640	9.96	10.240	10.174	4.44	4.251	4.593	9.73	9.415	9.291
3	6.02	5.818	6.234	4.16	3.084	3.477	9.92	10.742	10.348	7.56	7.996	8.041
4	7.86	8.102	8.064	7.23	7.415	7.025	8.75	9.092	9.837	9.33	9.601	9.649
5	7.21	7.277	6.997	5.31	4.997	5.043	10.86	11.621	11.362	9.27	8.721	8.639
6	7.01	6.729	7.067	9.93	10.404	10.011	4.32	3.829	4.141	8.46	8.346	8.507
7	8.51	8.632	8.982	8.10	8.349	8.739	7.68	7.648	6.869	9.42	9.937	9.974
8	6.34	5.943	5.651	5.49	4.954	4.237	7.05	6.953	7.785	8.01	8.034	8.025
9	7.71	7.592	7.707	6.49	6.393	7.233	7.43	7.118	7.305	9.45	9.105	9.335
10	8.00	7.959	7.707	7.19	7.678	7.233	7.83	7.340	7.305	9.20	9.646	9.335
11	8.13	8.058	7.707	6.59	6.822	7.233	7.92	7.703	7.305	9.46	9.178	9.335
12	7.01	7.318	7.707	7.20	7.379	7.233	7.28	7.204	7.305	9.13	9.195	9.335
13	7.39	7.606	7.707	7.56	7.893	7.233	7.14	7.161	7.305	9.45	9.550	9.335

[a] Observed mean: Average of 36 results for trained panel.
[b] Observed mean: Average of 32 results for consumer panel.
[c] Estimated mean: Observed mean + block estimated effect according to BIB design.
[d] Expected mean: Calculated from response model.
[e] Formulas described in Table 1.

Table 4.3. Mean scores of 20% blackberry juice level drinks for thirteen treatments.

	MEAN FLAVOR INTENSITY SCORE			MEAN SWEETNESS SCORE			MEAN SOURNESS SCORE			MEAN OVERALL DESIRABILITY SCORE		
FORMULA NUMBER[e]	Observed[a] Means	Adjusted[c] Means	RSM[d] Expected	Observed Means	Adjusted Means	RSM Expected	Observed[b] Means	Adjusted Means	RSM Expected	Observed[b]	Combined[e] Estimated	RSM Expected
1	6.69	5.536	5.824	6.19	5.536	6.317	3.06	5.148	4.153	8.33	8.580	7.942
2	8.19	8.939	8.126	9.17	8.939	9.853	5.11	5.326	4.344	8.63	8.695	7.882
3	6.32	4.017	5.952	4.60	4.017	3.730	10.52	11.447	11.415	7.35	7.166	8.099
4	7.89	7.898	7.919	7.77	7.898	7.743	8.27	8.512	8.493	9.39	9.077	9.835
5	6.56	4.885	6.359	5.18	4.885	5.327	10.48	11.165	10.991	8.85	9.800	8.629
6	6.23	9.717	6.416	9.3	9.717	8.648	3.12	1.735	2.923	6.44	6.086	7.137
7	8.80	9.909	9.032	9.25	9.969	9.502	6.34	5.782	6.280	9.29	9.524	9.588
8	5.83	4.385	6.014	4.65	4.385	4.165	8.02	7.694	8.211	8.40	8.588	8.404
9	8.54	7.505	7.922	7.19	7.505	7.218	6.73	6.069	6.819	8.58	8.211	8.969
10	6.84	6.974	7.922	6.65	6.974	7.218	6.43	6.103	6.819	9.61	9.826	8.969
11	7.47	7.639	7.922	7.26	7.639	7.218	6.68	6.649	6.819	9.05	8.795	8.969
12	8.01	6.671	7.922	6.90	7.218	7.218	7.43	8.144	6.819	8.93	8.625	8.969
13	7.88	7.301	7.922	7.52	7.301	7.218	6.73	7.131	6.819	9.47	9.387	8.969

a Observed mean: Average of 36 results for trained panel.
b Observed mean: Average of 32 results for consumer panel.
c Estimated mean: Observed mean + block estimated effect according to BIB design.
d Expected mean: Calculated from response model.
e Formulas described in Table 1.

Table 5.1. Response surface model coefficients relating formula variations of blackberry juice drinks to attribute ratings, for the 10% juice level drinks.

COEFFICIENTS	BLACKBERRY FLAVOR INTENSITY	SWEETNESS INTENSITY	SOURNESS INTENSITY	OVERALL DESIRABILITY
Constant (b_0)	7.839***	7.185***	7.985***	9.210***
Acid (b_1)	-0.078	-1.552***	2.938***	0.672***
Sugar (b_2)	1.110**	1.741***	-0.851*	0.028
$(\text{Acid})^2$ (b_1^2)	-0.635	0.161	-0.824**	-0.839***
Acid x Sugar (b_1b_2)	0.314	0.039	-1.465*	0.107
$(\text{Sugar})^2$ (b_2^2)	-0.146	0.021	-0.404	-0.345*
Multiple R^2	0.767	0.964	0.946	0.913
F ratio	4.601*	37.516***	24.390***	15.732***
Lack of Fit[a]	2.448	0.441	1.345	1.183

[a] Degree of freedom 3,4.

* Significant at $p < 0.05$.

** Significant at $p < 0.01$.

*** Significant at $p < 0.001$.

Table 5.2. Response surface model coefficients relating formula variations of blackberry juice drinks to attribute ratings, for the 15% juice level drinks.

COEFFICIENTS	BLACKBERRY FLAVOR INTENSITY	SWEETNESS INTENSITY	SOURNESS INTENSITY	OVERALL DESIRABILITY
Constant (b_0)	7.707***	7.233***	7.305***	9.335***
Acid (b_1)	-0.025	-1.757***	2.553***	0.047
Sugar (b_2)	1.178***	1.592***	-0.324	0.671***
$(\text{Acid})^2$ (b_1^2)	-0.337	0.147	0.223	-0.381**
Acid x Sugar (b_1b_2)	-0.263	0.182	0.069	0.133
$(\text{Sugar})^2$ (b_2^2)	-0.195	-0.373	0.011	-0.155
Multiple R^2	0.914	0.936	0.944	0.939
F ratio	14.845**	20.397***	23.692***	21.478***
Lack of Fit[a]	2.957	1.438	17.308**	4.106

[a] Degree of freedom 3,4.

* Significant at $p < 0.05$.

** Significant at $p < 0.01$.

*** Significant at $p < 0.001$.

Table 5.3. Response surface model coefficients relating formula variations of blackberry juice drinks to attribute ratings, for the 20% juice level drinks.

COEFFICIENTS	BLACKBERRY FLAVOR INTENSITY	SWEETNESS INTENSITY	SOURNESS INTENSITY	OVERALL DESIRABILITY
Constant (b_0)	7.922***	7.218***	6.819***	8.969**
Acid (b_1)	-0.020	-1.174**	2.853***	0.528
Sugar (b_2)	1.067**	1.887***	-0.683	0.419
$(\text{Acid})^2$ (b_1^2)	-0.768*	-0.115	0.069	-0.543
Acid x Sugar (b_1b_2)	-0.084	0.120	-0.778	0.499
$(\text{Sugar})^2$ (b_2^2)	-0.200	-0.192	0.213	0.014
Multiple R^2	0.844	0.915	0.912	0.495
F ratio	17.551**	14.877**	14.586***	1.374[NS]
Lack of Fit[a]	0.348	6.617	1.764	4.106

[a] Degree of freedom 3,4.

* Significant at $p < 0.05$.

** Significant at $p < 0.01$.

*** Significant at $p < 0.001$.

Table 6. °Brix:acid ratios, sweetness:sourness ratios, and desirability ratings for drinks made at three blackberry juice levels.

Formula	°Brix:acid ratio[a]	Sweetness:Sourness Ratio[b] 10% (juice level)	15%	20%	Desirability 10% (juice level)	15%	20%
1	35.0	1.77	1.13	2.02	7.43	8.60	8.33
2	42.7	1.83	2.24	1.79	6.99	9.73	8.63
3	19.7	0.43	0.42	0.44	8.43	7.56	7.35
4	24.1	0.90	0.85	0.94	8.81	9.33	9.39
5	20.0	0.56	0.49	0.49	8.16	9.27	8.85
6	46.7	3.02	2.30	2.98	6.84	8.46	6.44
7	32.0	1.63	1.25	1.46	8.65	9.42	9.29
8	24.0	0.68	0.78	0.58	8.83	8.01	8.40
9 (middle points)[c]	28.0	0.94	0.93	1.05	9.22	9.34	9.13

[a] From Table 1

[b] From observed values in Table 4.1 - 4.3.

[c] Average values at five middle points.

Table 7. The regression model coefficients relating ^{o}Brix:acid ratio to sweetness, sourness, and sweetness-sourness ratio in log-log unit, for all the three juice level drinks.

Coefficients	Sweetness Intensity 10%	15% (juice level)	20%	Sourness Intensity 10%	15% (juice level)	20%	Sweetness:Sourness Ratio 10%	15% (juice level)	20%
Intercept	-0.247	-0.399	-0.245	2.632***	2.277***	2.739***	-2.869***	-2.662***	-2.989***
Slope	0.753***	0.846***	0.736*	-1.242***	-0.976***	-1.328***	1.989***	1.813***	2.065***
F ratio	23.327**	34.741***	11.486*	44.282***	60.322***	28.258**	107.361***	108.106***	83.964***
Adjusted R-square	0.736	0.808	0.567	0.844	0.881	0.773	0.930	0.940	0.912

* Significant at $p < 0.05$.

** Significant at $p < 0.01$.

*** Significant at $p < 0.001$.

Table 8.1 Regression coefficients of desirability vs. °Brix:acid ratio and sweetness:sourness ratios, for the 10% juice levels.

Linear Model

	°Brix:Acid Ratio	Sweetness:Sourness Ratio
intercept	10.261***	9.178***
slope	-0.069*	-0.786*
F ratio	11.106*	9.535*
adjusted R-square	-0.558	0.516

Curvilinear Model

	°Brix:Acid Ratio
intercept	5.701
b_1	0.234
b_2	-0.004
F ratio	9.938*
adjusted R-square	0.690

b_s Regression coefficients

* Significant at $p < 0.05$.

** Significant at $p < 0.01$.

*** Significant at $p < 0.001$.

Table 8.2 Curvilinear regression coefficients of desirability vs. °Brix:acid ratios and sweetness:sourness ratios, for the 20% juice level.

	°Brix:Acid Ratio	Sweetness:Sourness Ratio
intercept	0.626	7.091***
b_1	0.559*	2.974*
b_2	-0.009*	-1.089**
F ratio	5.10*	11.88**
adjusted R-square	0.506	0.731

b_s Regression coefficients.

* Significant at $p < 0.05$.

** Significant at $p < 0.01$.

*** Significant at $p < 0.001$.

Table 9.1. The blackberry flavor summary ratings of the blackberry juice drinks based on just right scale ratings by the consumer panel.

Sugar Level[a]	Juice Level	Acid Level[b] low (Group I)		Acid Level[b] medium (Group II)		Acid Level[b] high (Group III)	
		Formula 1		Formula 8		Formula 3	
	10%	too weak	(6.80)[d]	too weak-	(6.18)	too weak	(5.89)
LOW	15%	too weak	(6.09)	too weak	(6.34)	just right-	(6.02)
(Group I)	20%	too weak	(6.69)	too weak	(5.83)	just right-	(6.32)
		Formula 6		Formula 9[c]		Formula 5	
	10%	too weak-	(6.85)	just right-	(7.42)	just right-	(7.59)
MEDIUM	15%	too weak-	(7.01)	just right-	(7.45)	just right-	(7.21)
(Group II)	20%	too weak-	(6.23)	just right-	(7.75)	just right-	(6.56)
		Formula 2		Formula 7		Formula 4	
	10%	too weak-	(8.01)	just right-	(9.00)	just right	(8.00)
HIGH	15%	just right-	(8.34)	just right-	(8.51)	just right	(7.86)
(Group III)	20%	just right-	(8.19)	just right-	(8.80)	just right	(7.89)

ab Refer to Table 1.

c From the five middle points by taking the average values.

d Attached numerical values were observed mean blackberry flavor intensity scores rated by trained panel based on line scale.

-,+ Following any term means slightly lower or slightly higher than that particular term. For example, "just right +" means ratings were between just right and slightly too much.

Table 9.2. The sweetness distributions of the blackberry juice drinks based on just right scale ratings by the consumer panel.

		Acid Level[b]					
		low (Group I)		medium (Group II)		high (Group III)	
Sugar Level[a]	Juice Level						
		Formula 1		Formula 8		Formula 3	
LOW (Group I)	10%	just right+	(7.07[d])	just right	(5.83)	just right-	(4.50)
	15%	mixed	(7.01)	just right	(5.49)	just right-	(4.16)
	20%	mixed	(6.19)	just right	(4.65)	not enough-	(4.60)
		Formula 6		Formula 9[c]		Formula 5	
MEDIUM (Group II)	10%	too sweet	(9.44)	just right	(7.57)	not enough	(5.55)
	15%	too sweet	(9.93)	just right	(7.01)	mixed	(5.38)
	20%	too sweet	(9.30)	just right	(7.10)	mixed	(5.18)
		Formula 2		Formula 7		Formula 4	
HIGH (Group III)	10%	too sweet+	(9.89)	just right+	(9.36)	just right	(7.37)
	15%	just right+	(9.96)	just right+	(8.10)	just right	(7.23)
	20%	too sweet++	(9.17)	mixed	(9.25)	sl. too sweet+	(7.79)

ab Refer to Table 1.

c From the five middle points by taking the average values.

d Attached numerical values were observed mean sweetness scores rated by trained panel based on line scale.

-,+ Following any term means slightly lower or slightly higher than that particular term. For example, "just right +" means ratings were between just right and slightly too much.

Table 9.3. The sourness distributions of the blackberry juice drinks based on just right scale ratings by the consumer panel.

		Acid Level[b]					
Sugar Level[a]	Juice Level	low (Group I)		medium (Group II)		high (Group III)	
		Formula 1		Formula 8		Formula 3	
	10%	not enough	(3.99[d])	just right+	(8.56)	sl. too sour	(10.57)
LOW	15%	just right·	(6.22)	just right	(7.05)	bimodel	(9.92)
(Group I)	20%	not enough	(3.06)	just right	(8.02)	too sour	(10.52)
		Formula 6		Formula 9[c]		Formula 5	
	10%	not enough	(3.13)	just right	(7.69)	too sour	(9.96)
MEDIUM	15%	just right··	(4.32)	just right	(7.52)	just right+	(10.86)
(Group II)	20%	not enough·	(3.12)	just right	(6.81)	just right+	(10.48)
		Formula 2		Formula 7		Formula 4	
	10%	not enough	(5.41)	just right	(5.73)	just right	(8.19)
HIGH	15%	not enough	(4.44)	just right	(7.68)	just right+	(8.75)
(Group III)	20%	not enough·	(5.11)	just right·	(6.34)	just right	(8.27)

ab Refer to Table 1.

c From the five middle points by taking the average values.

d Attached numerical values were observed mean sourness scores rated by trained panel based on line scale.

·,+ Following any term means slightly lower or slightly higher than that particular term. For example, "just right +" means ratings were between just right and slightly too much.

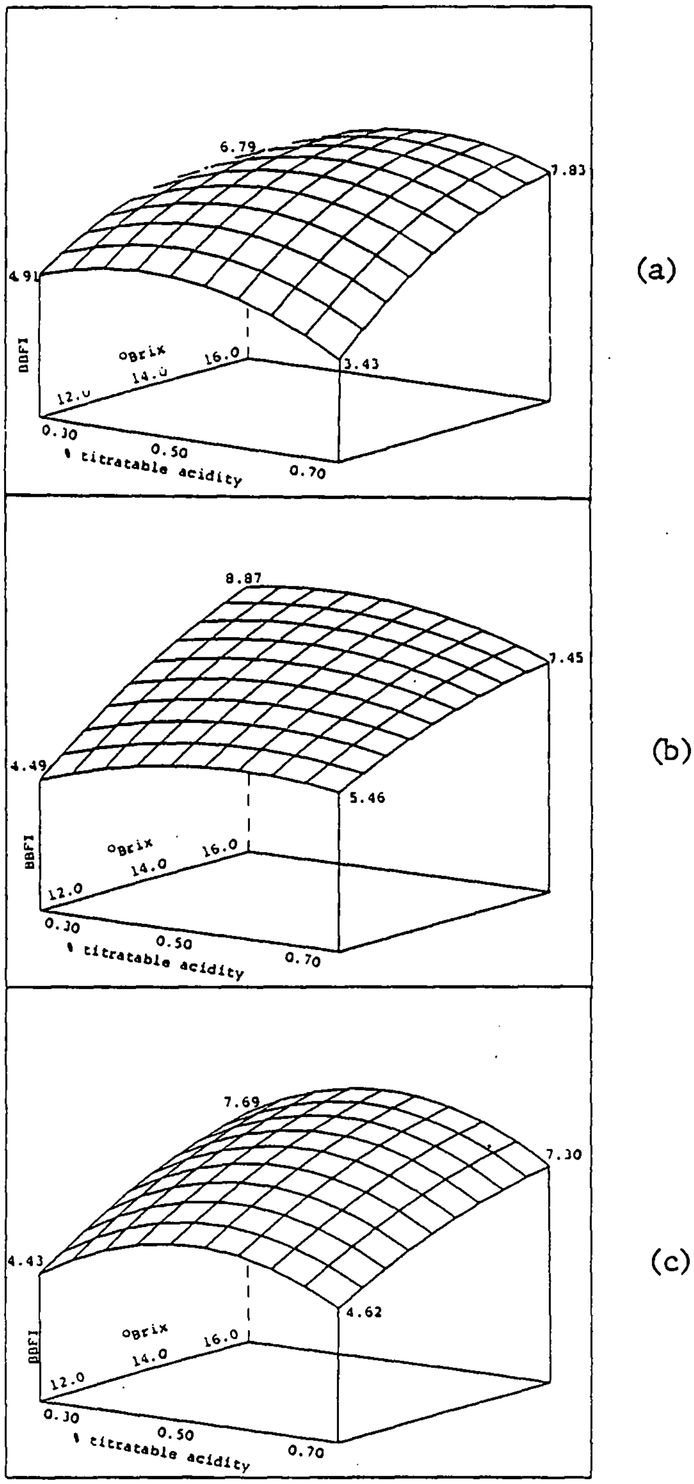


Fig. 1. Response surface of blackberry flavor intensity (BBFI), °Brix and % titratable acidity for the 10% (a), 15% (b), and 20% (c) juice level drinks, respectively.

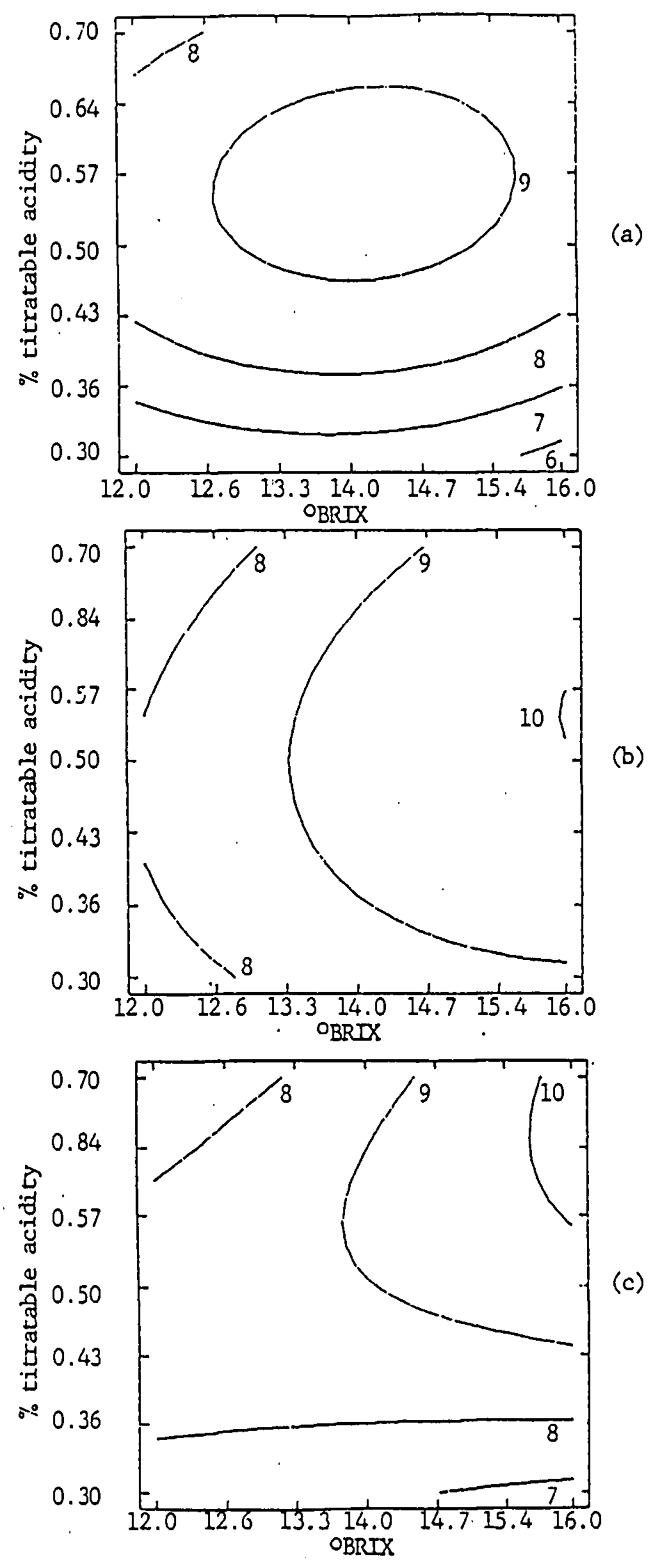
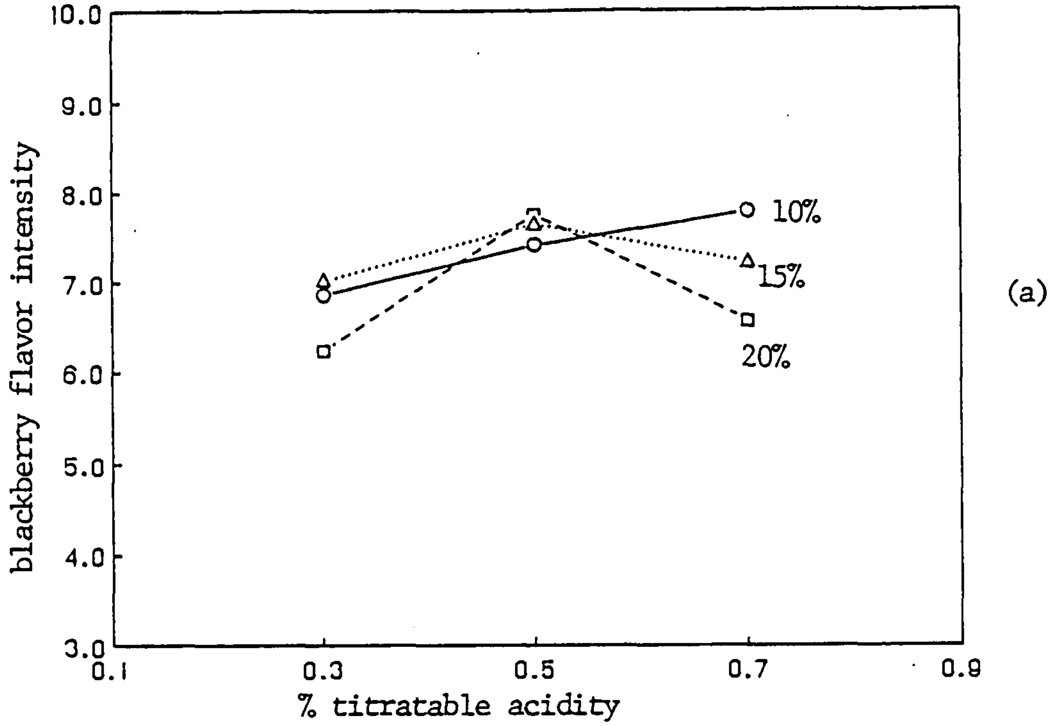


Fig. 2. Contour map of blackberry flavor intensity by °Brix and % titratable acidity for the 10% (a), 15% (b), and 20% (c) juice level drinks, respectively. Numbers (5-9) represent expected blackberry flavor intensities from RSM model.



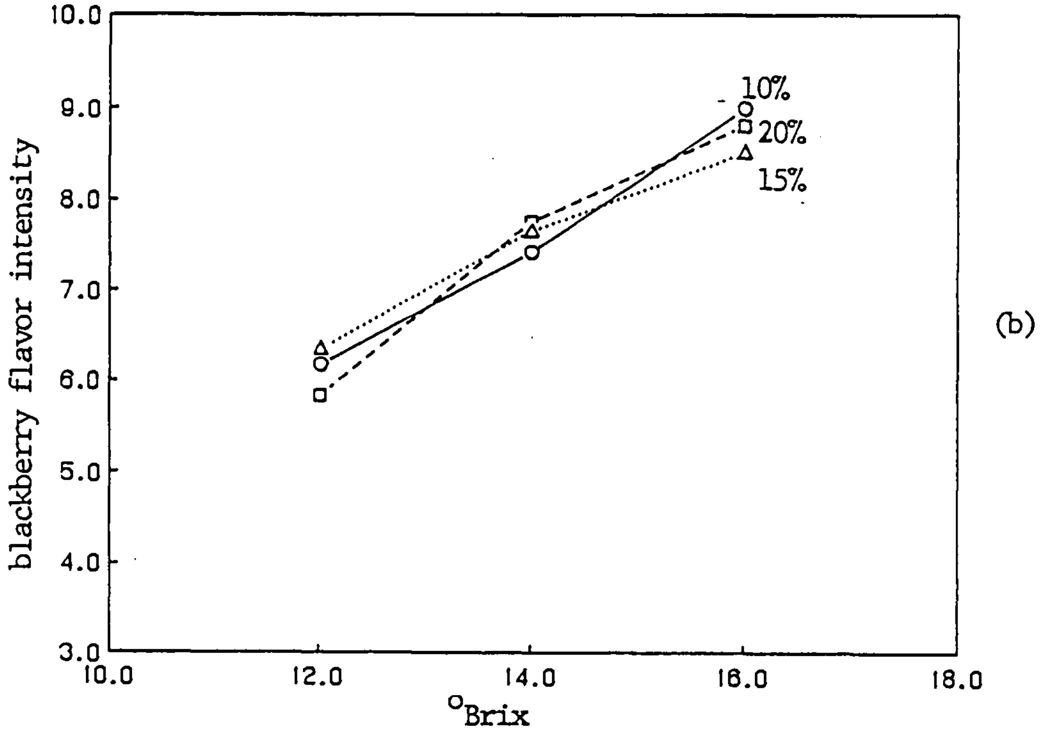


Fig. 3. The effect of titratable acidity at 14 °Brix (a) and °Brix at 0.5% titratable acidity (b) on blackberry flavor intensity observed mean scores for all three juice levels.

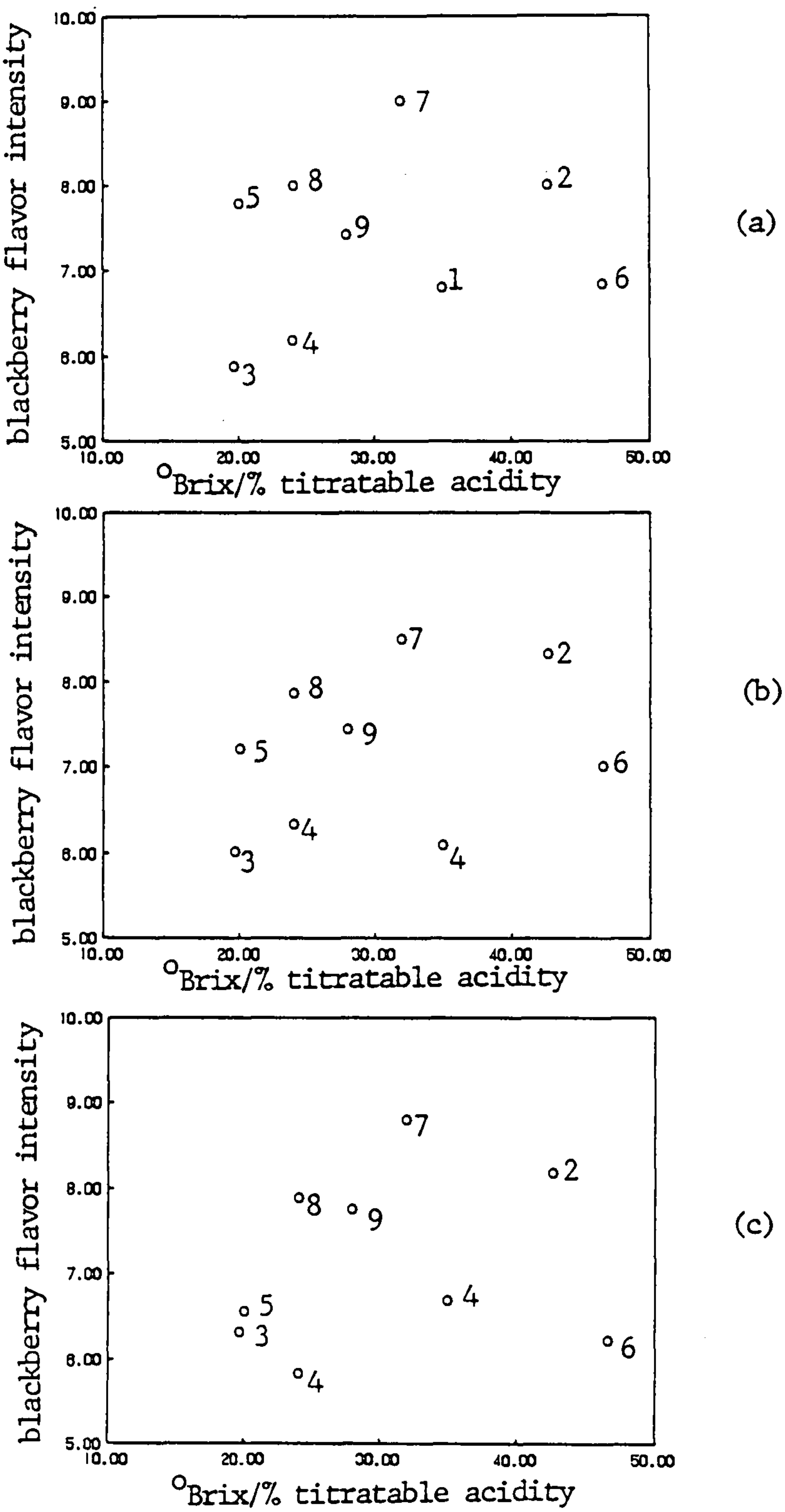


Fig. 4. Scatter plot of blackberry flavor intensity versus °Brix/% titratable acidity for the 10% (a), 15% (b), and 20% (c) juice level drinks, respectively. Numbers (1-9) represent different formulations.

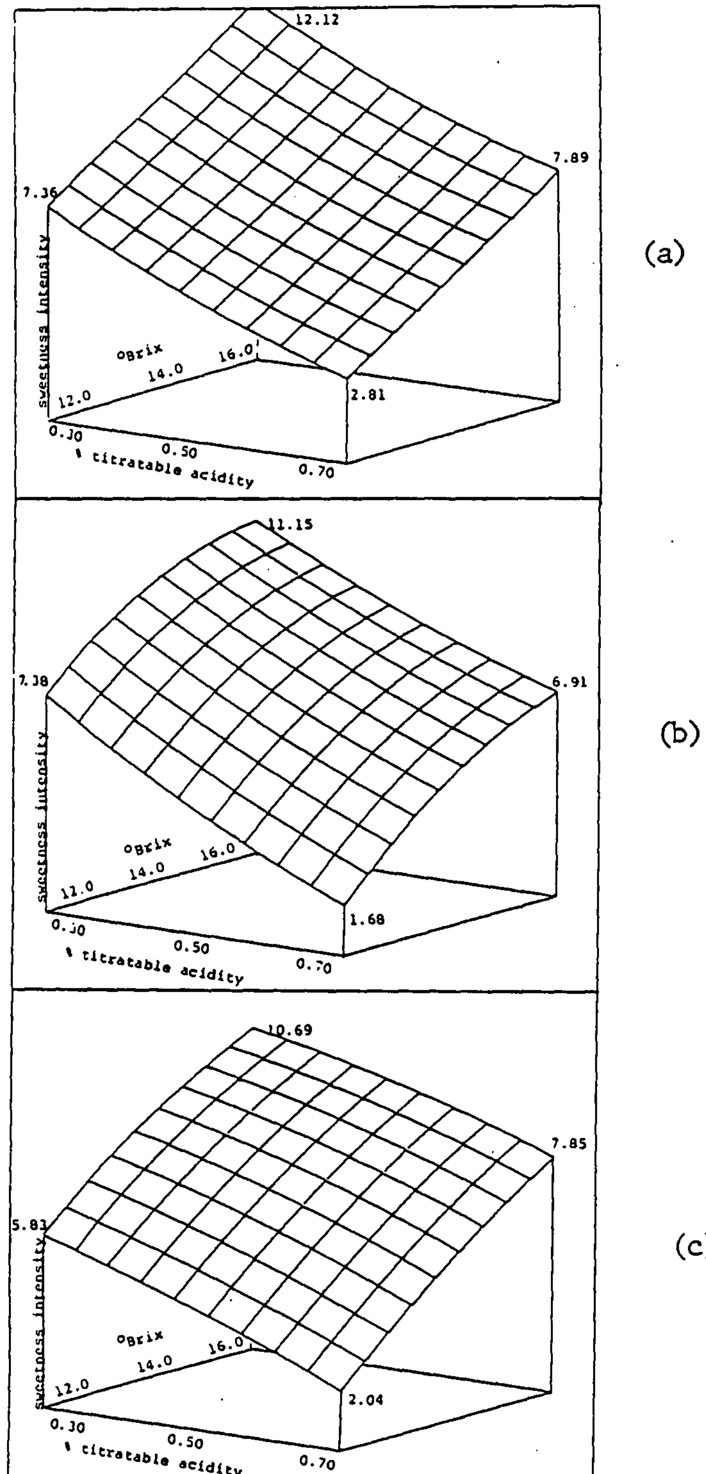


Fig. 5. Response surface of sweetness intensity, °Brix and % titratable acidity for the 10% (a), 15% (b), and 20% (c) juice level drinks, respectively.

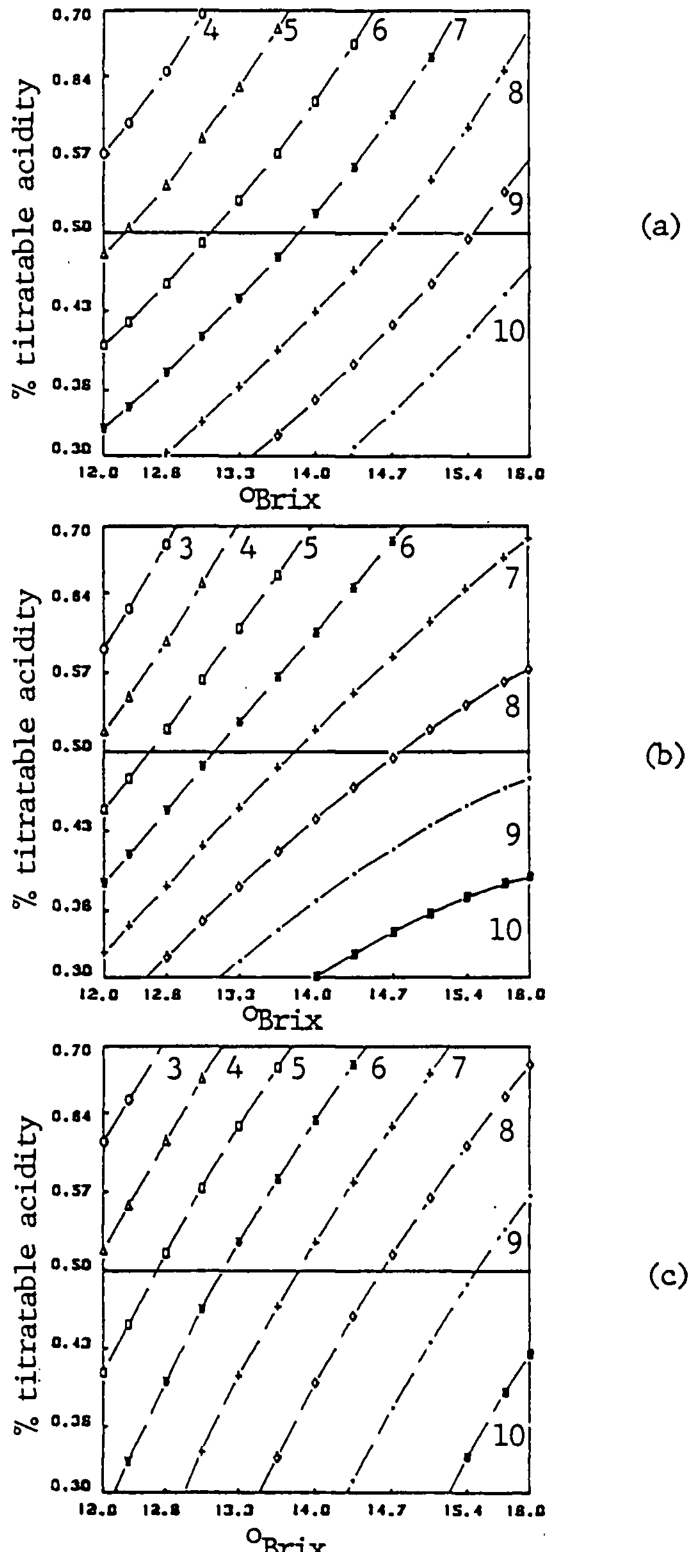


Fig. 6. Contour map of sweetness intensity by °Brix and % titratable acidity for the 10% (a), 15% (b), and 20% (c) juice level drinks, respectively. Numbers (3-10) represent expected sweetness intensities from RSM model.

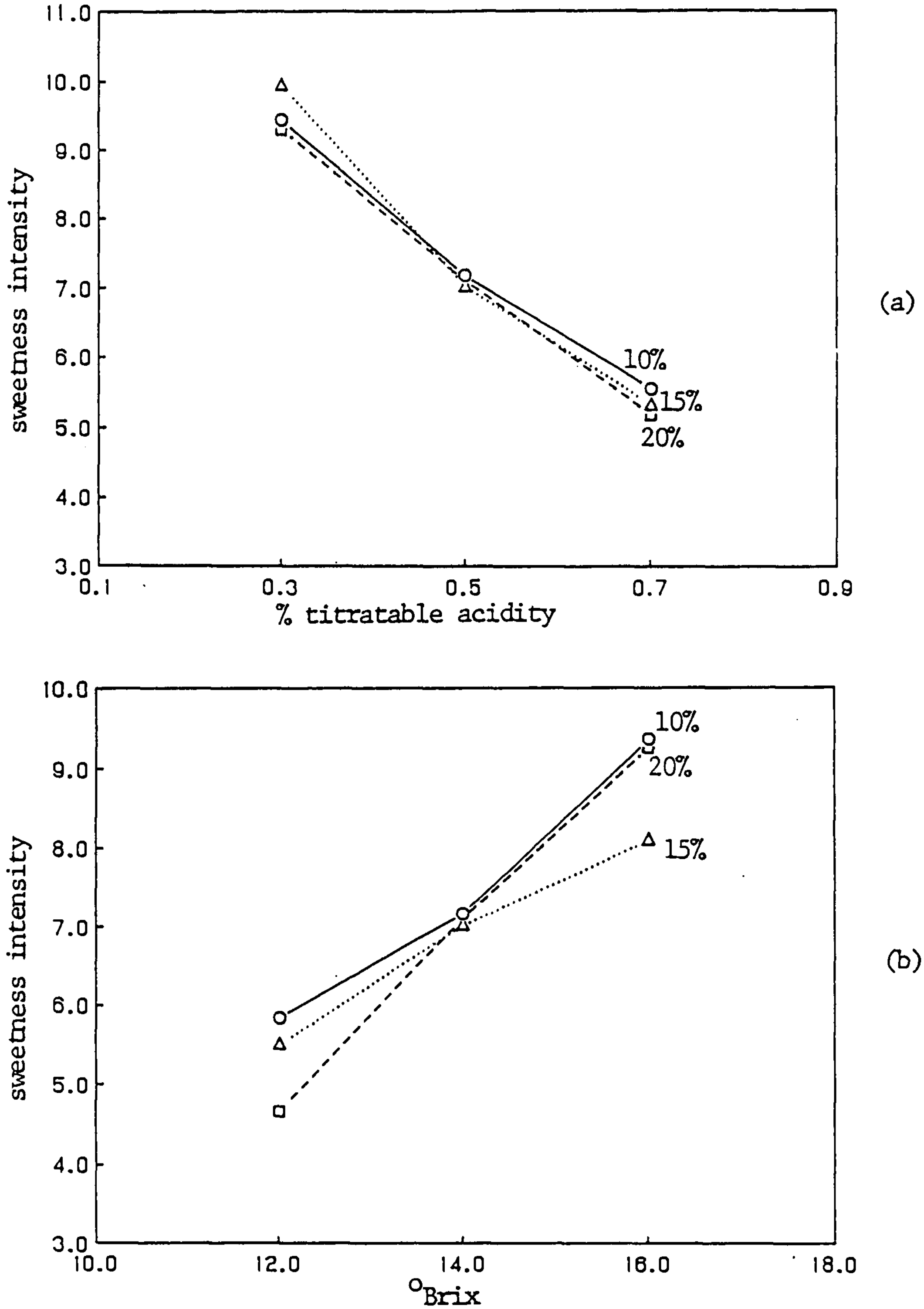


Fig. 7. The effect of titratable acidity at 14 °Brix (a) and °Brix at 0.5% titratable acidity (b) on sweetness intensity observed mean scores for all three juice levels.

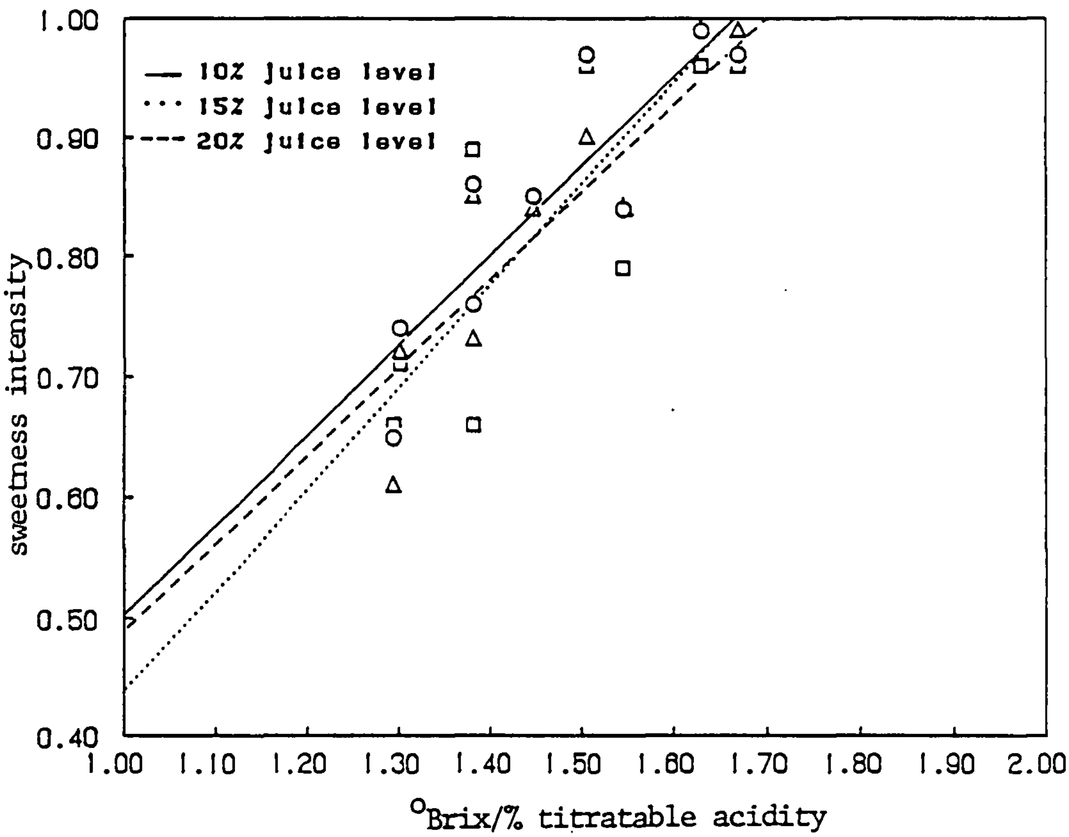


Fig. 8. Linear regression plot of sweetness intensity versus °Brix/% titratable acidity for all three juice levels (○ 10% juice level; △ 15% juice level; □ 20% juice level).

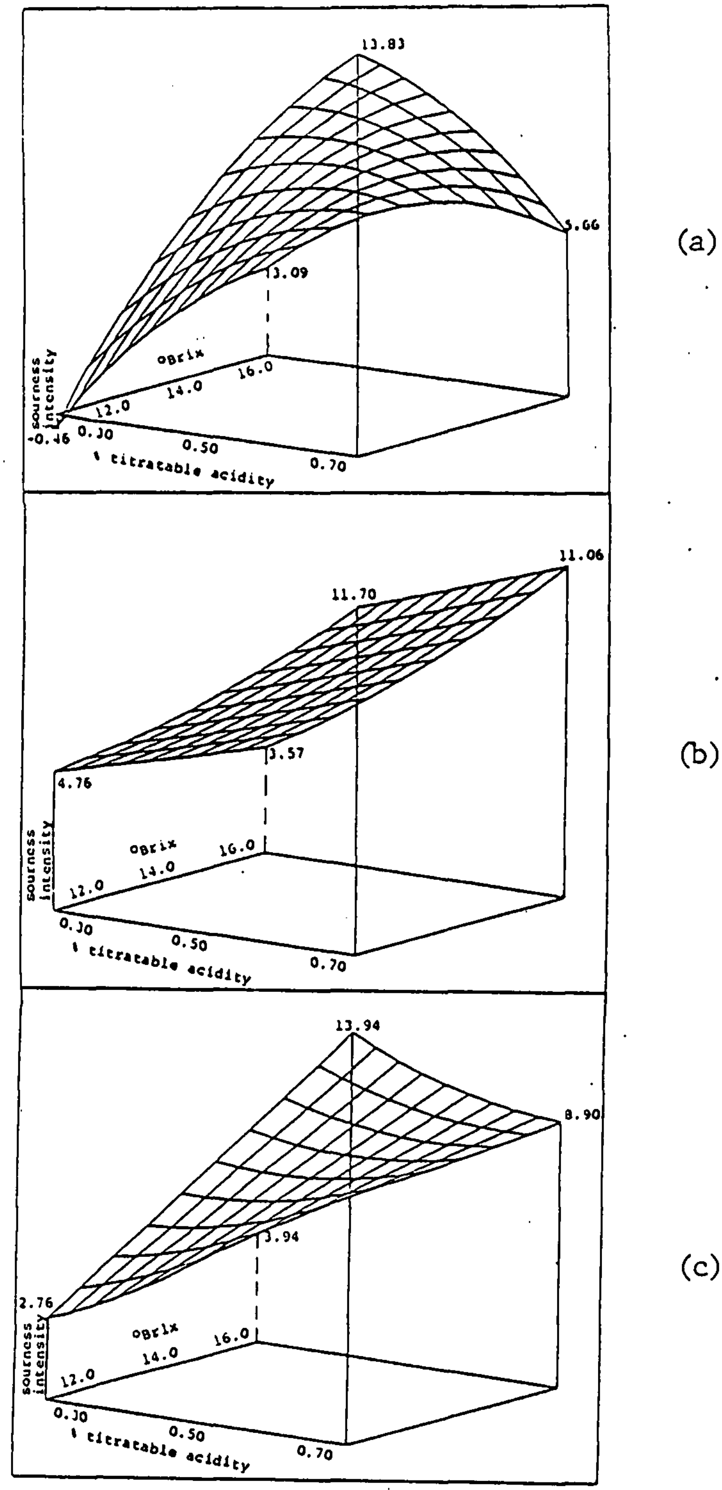


Fig. 9. Response surface of sourness intensity, °Brix and % titratable acidity for the 10% (a), 15% (b), and 20% (c) juice level drinks, respectively.

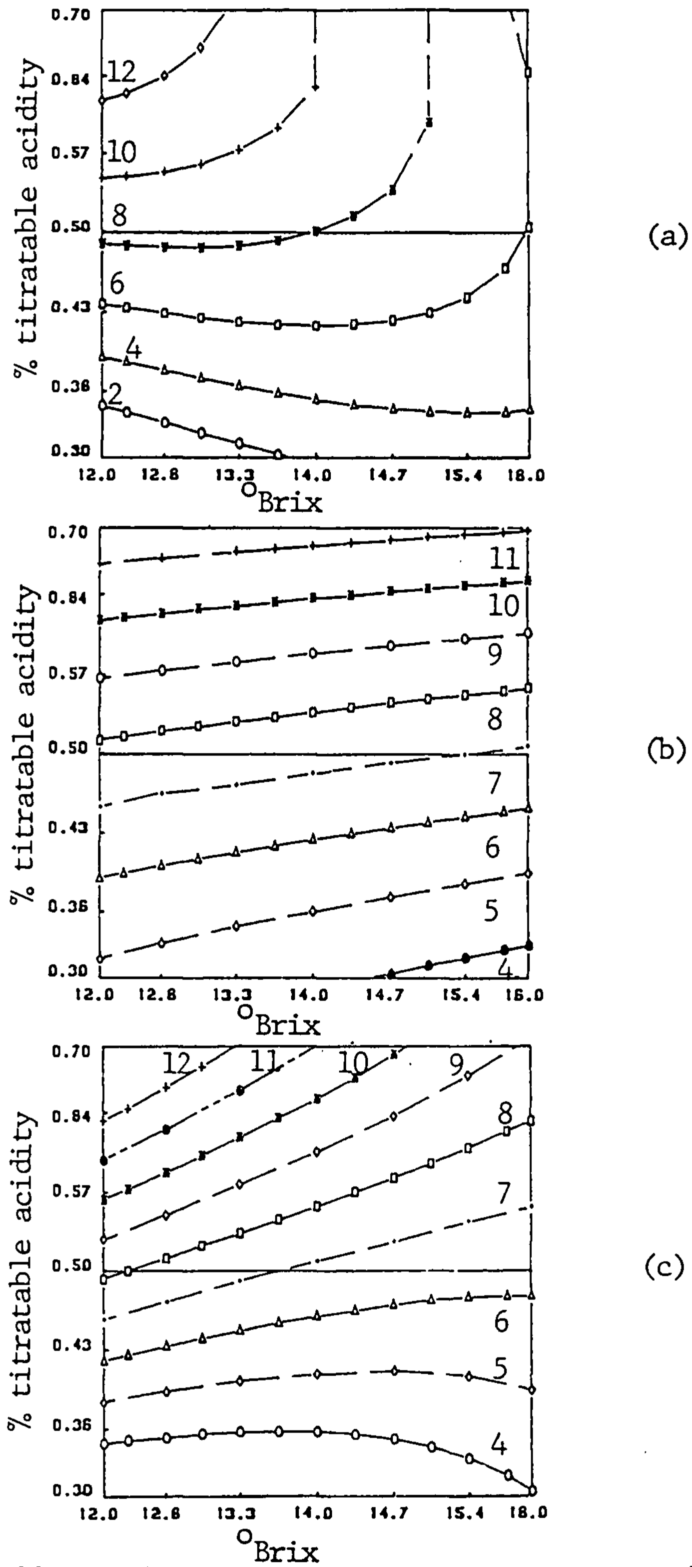


Fig. 10. Contour map of sourness intensity by °Brix and % titratable acidity for the 10% (a), 15% (b), and 20% (c) juice level drinks, respectively. Numbers (2-14) represent expected sourness intensities from RSM model.

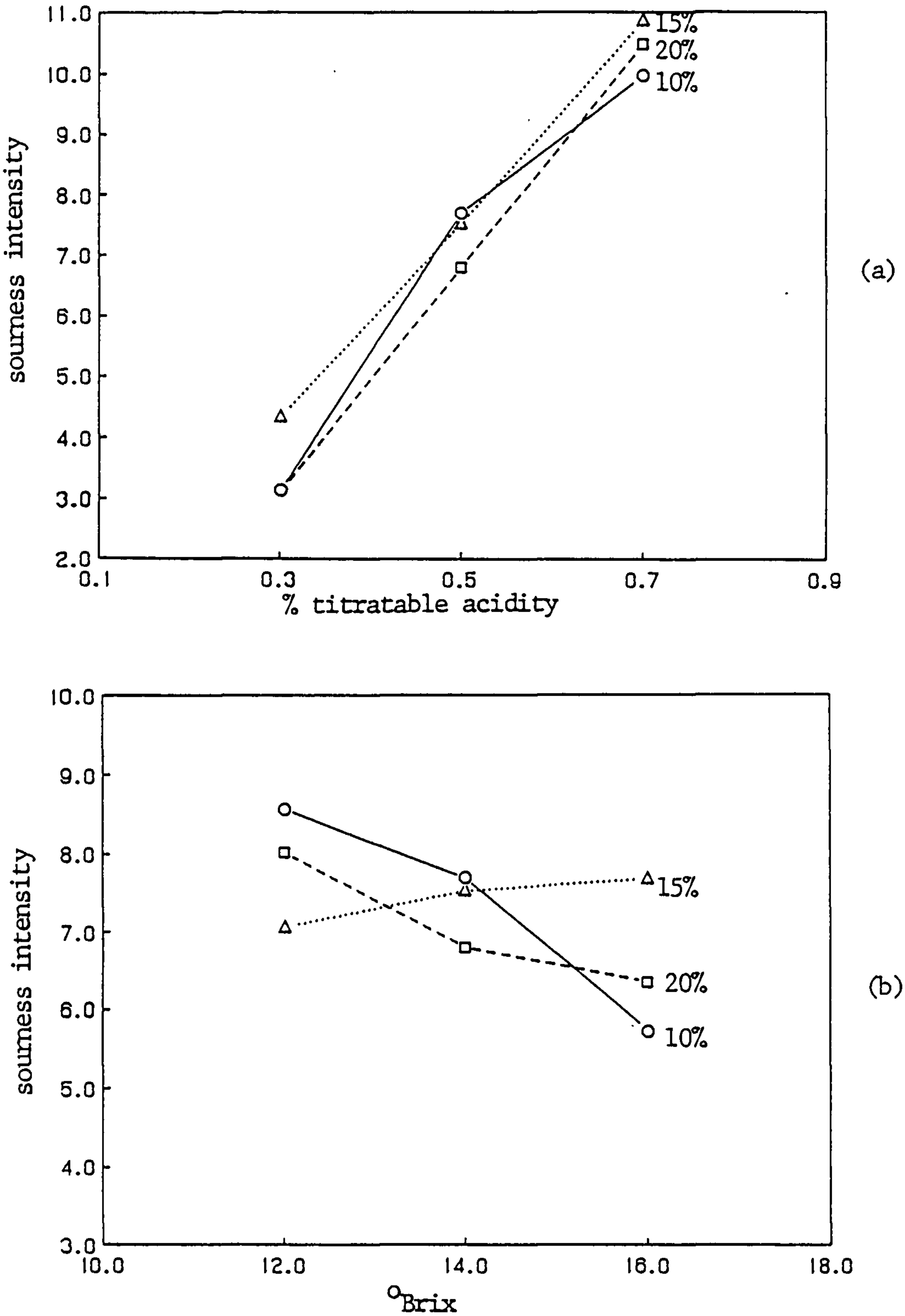


Fig. 11. The effect of titratable acidity at 14 °Brix (a) and °Brix at 0.5% titratable acidity (b) on sourness intensity observed mean scores for all three juice levels.

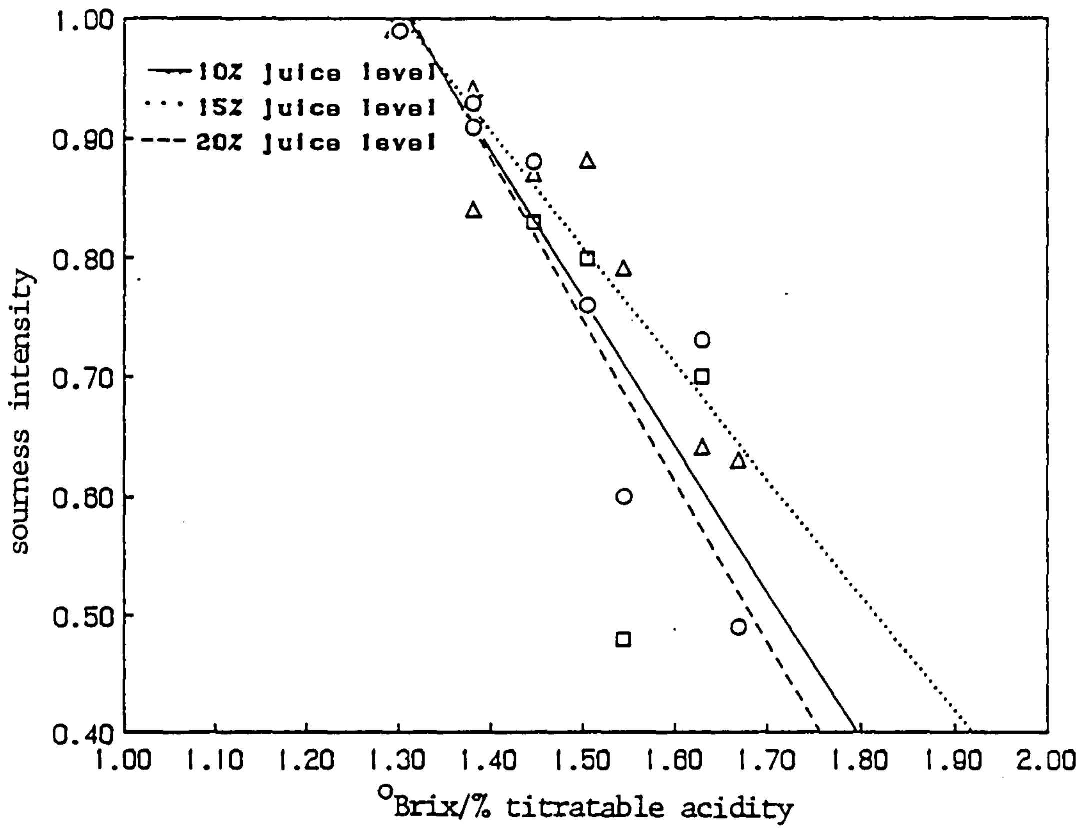


Fig. 12. Linear regression plot of sourness intensity versus °Brix/% titratable acidity for all three juice levels (○ 10% juice level; △ 15% juice level; □ 20% juice level).

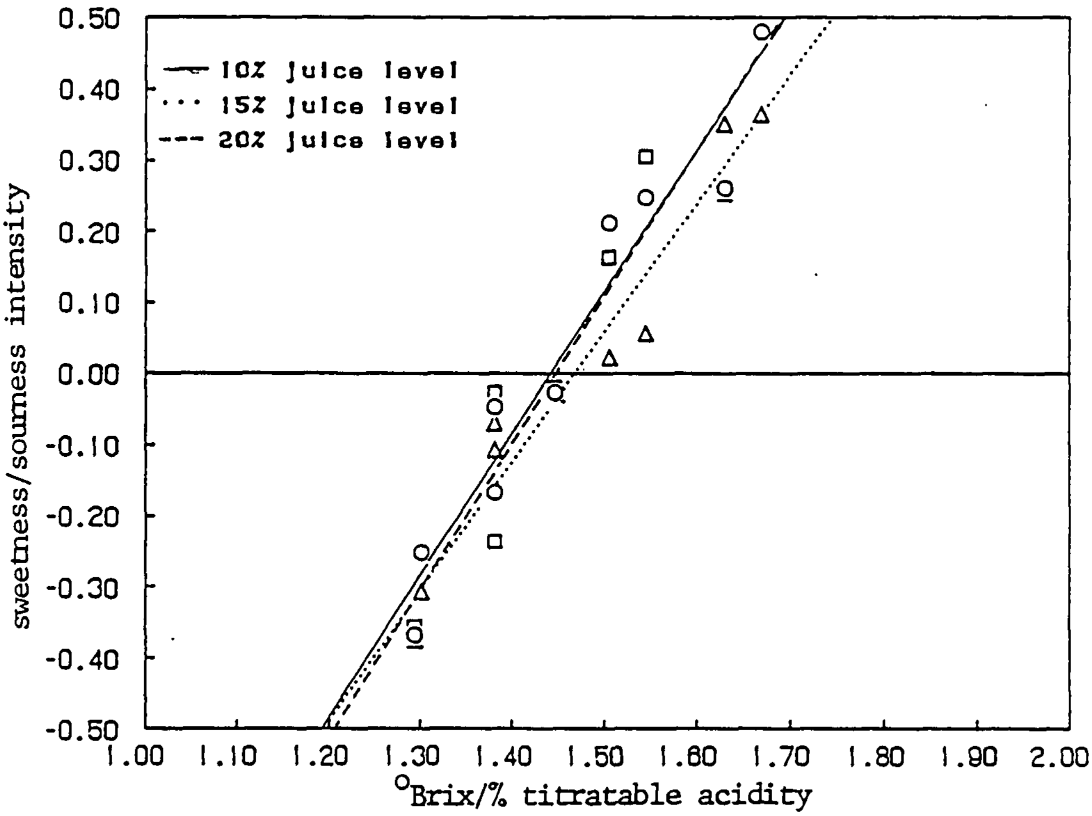


Fig. 13. Linear regression plot of sweetness/sourness intensity versus °Brix/% titratable acidity for all three juice levels (○ 10% juice level; △ 15% juice level; □ 20% juice level).

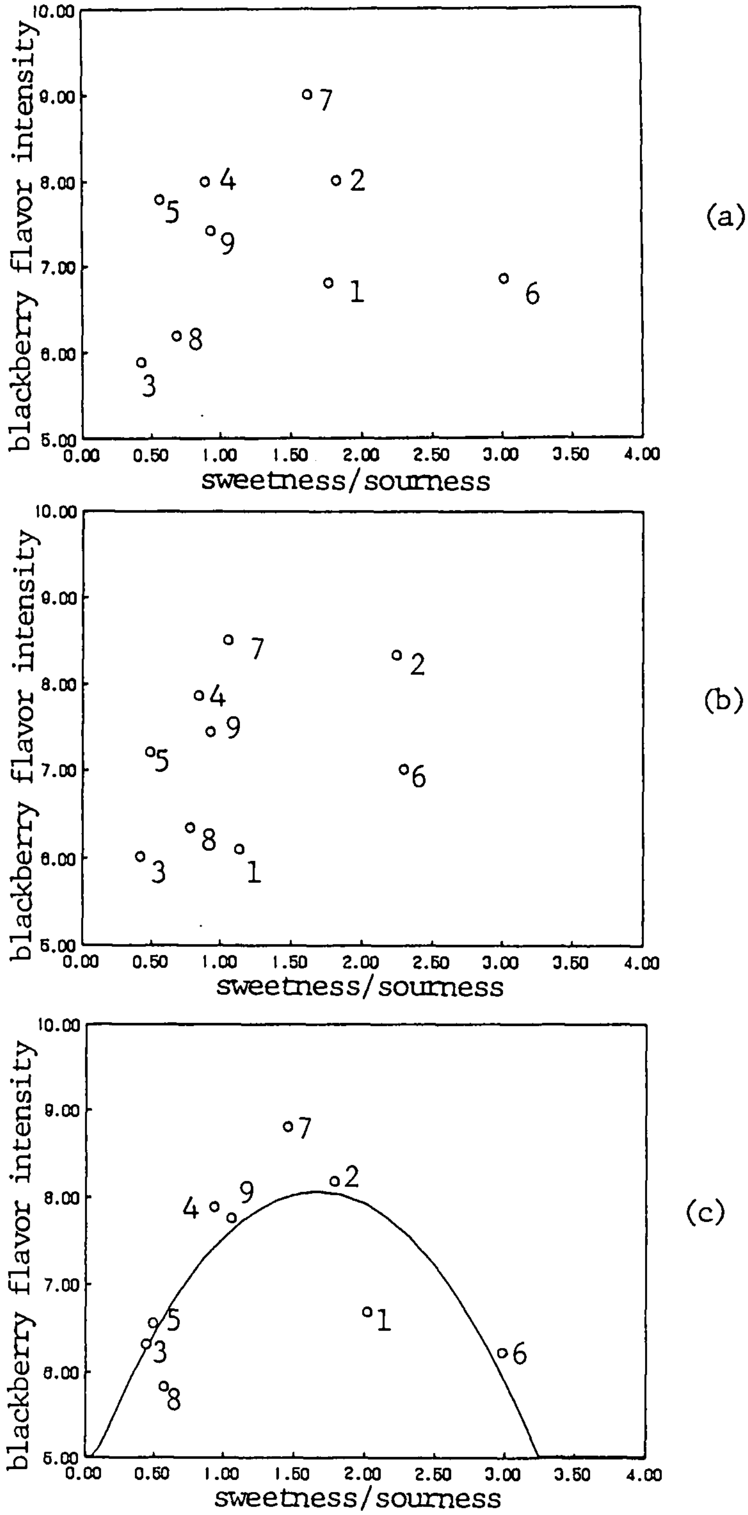


Fig. 14. Scatter plot of blackberry flavor intensity versus sweetness/sourness for the 10% (a), 15% (b), and 20% (c) juice level drinks, respectively. Numbers (1-9) represent different formulations.

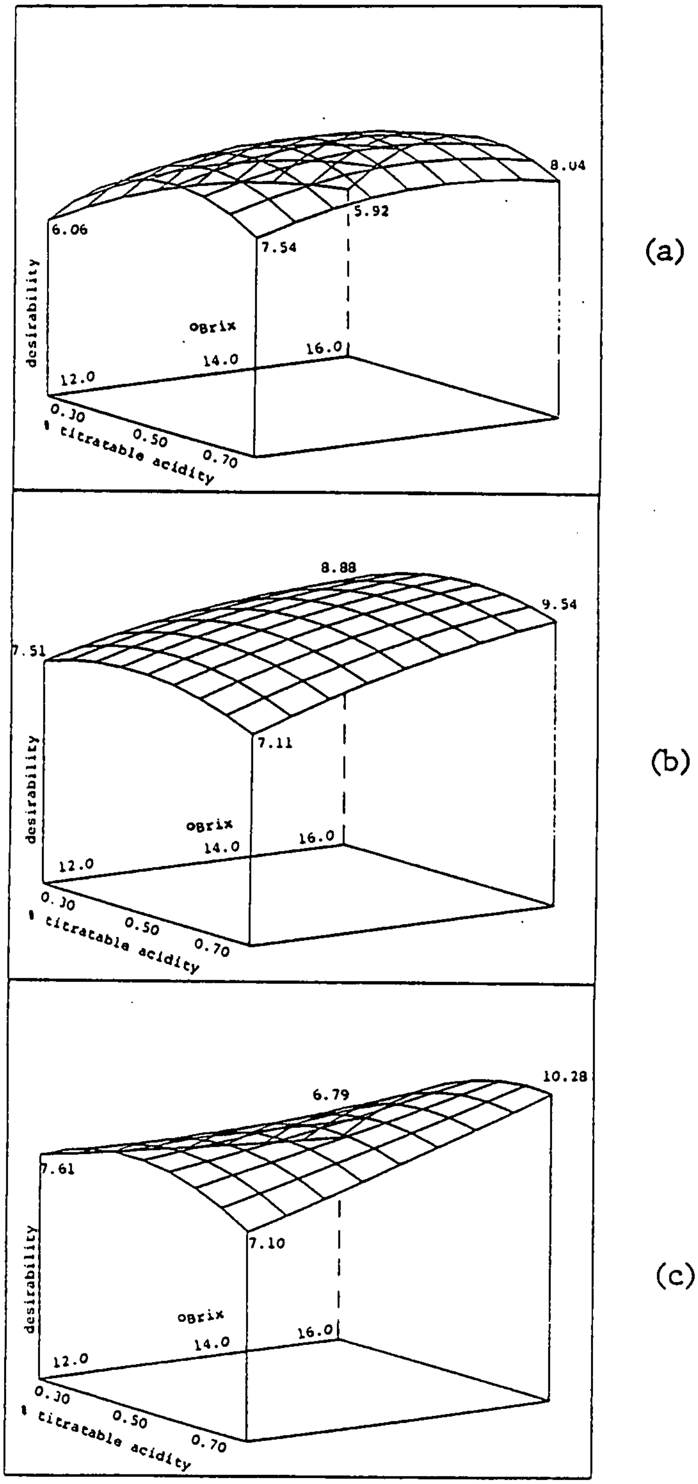


Fig. 15. Response surface of desirability, °Brix and % titratable acidity for the 10% (a), 15% (b), and 20% (c) juice level drinks, respectively.

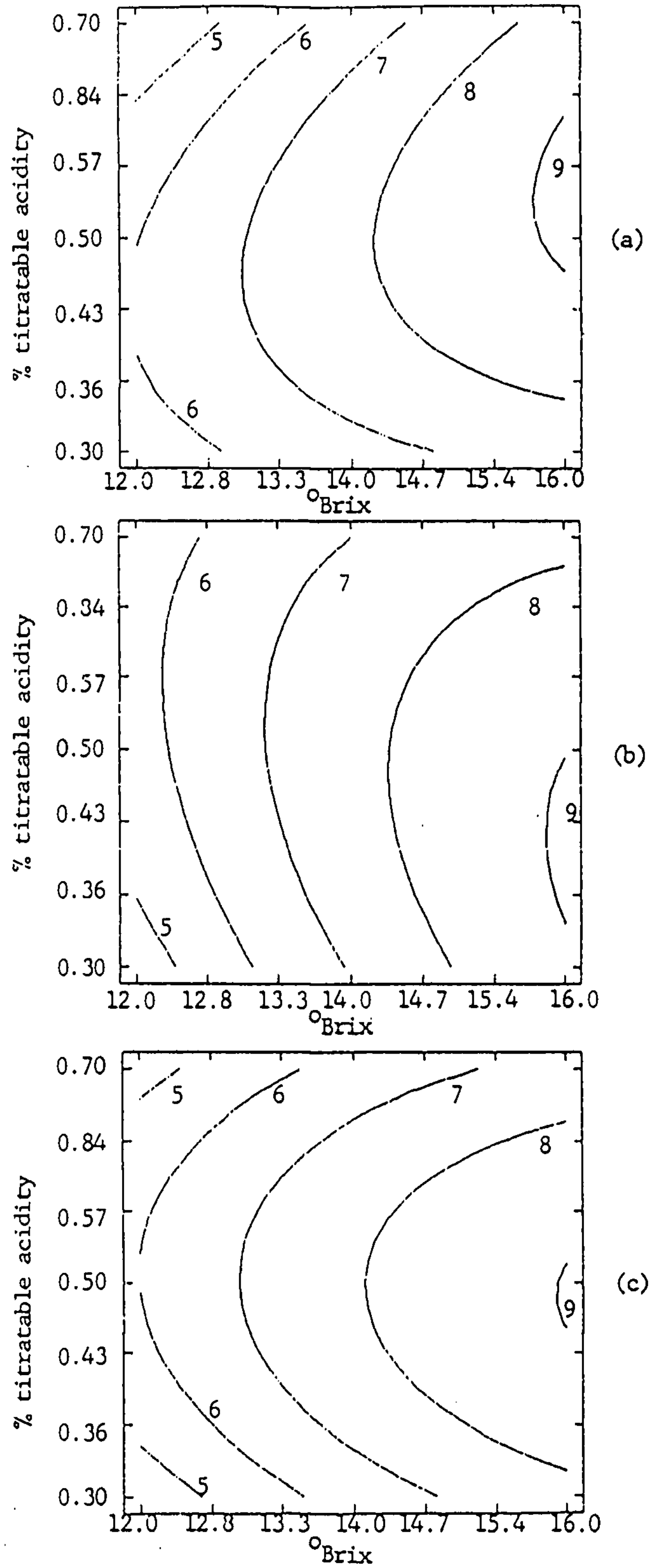
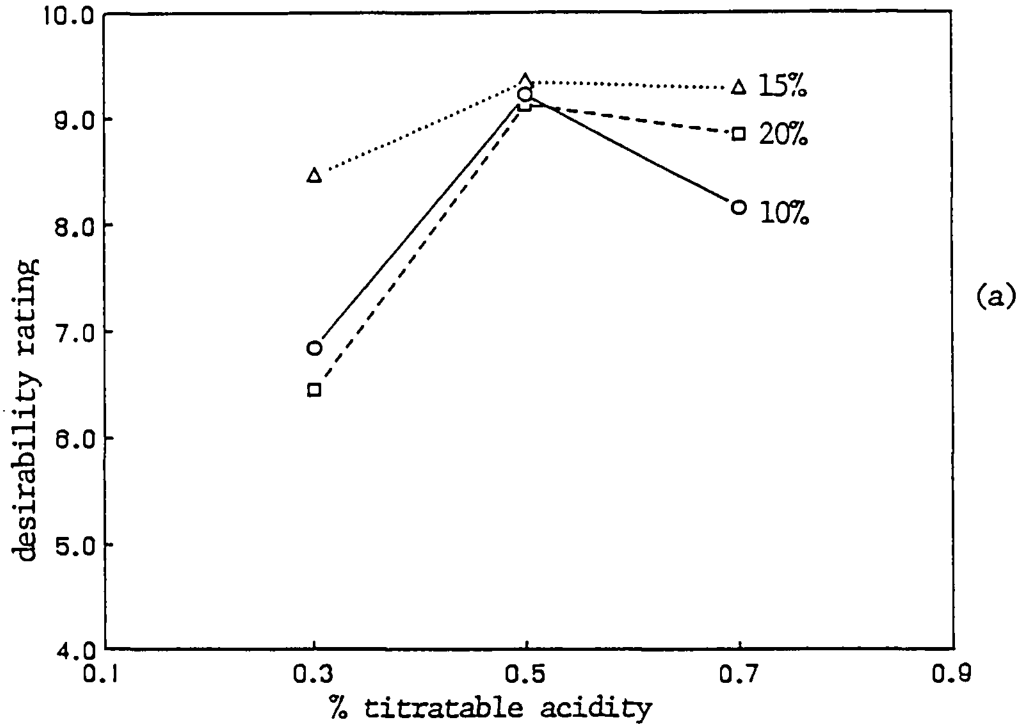


Fig. 16. Contour map of desirability ratings by °Brix and % titratable acidity for the 10% (a), 15% (b), and 20% (c) juice level drinks, respectively. Numbers (7-10) represent expected desirability ratings from RSM model.



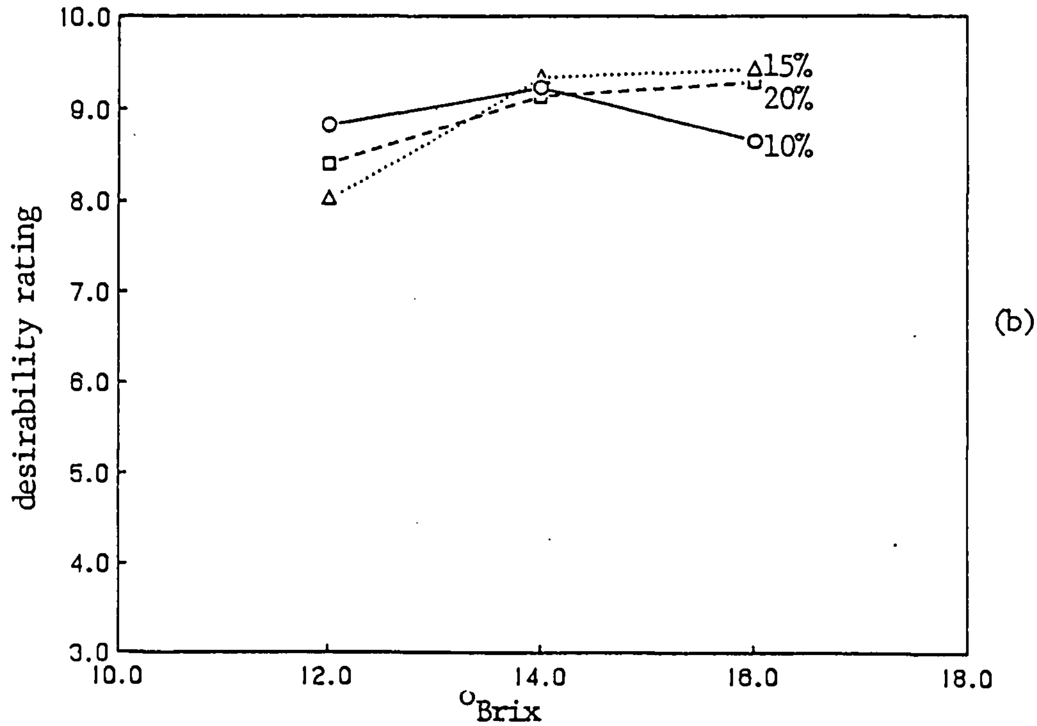


Fig. 17. The effect of titratable acidity at 14 °Brix (a) and °Brix at 0.5% titratable acidity (b) on desirability rating observed mean scores for all three juice levels.

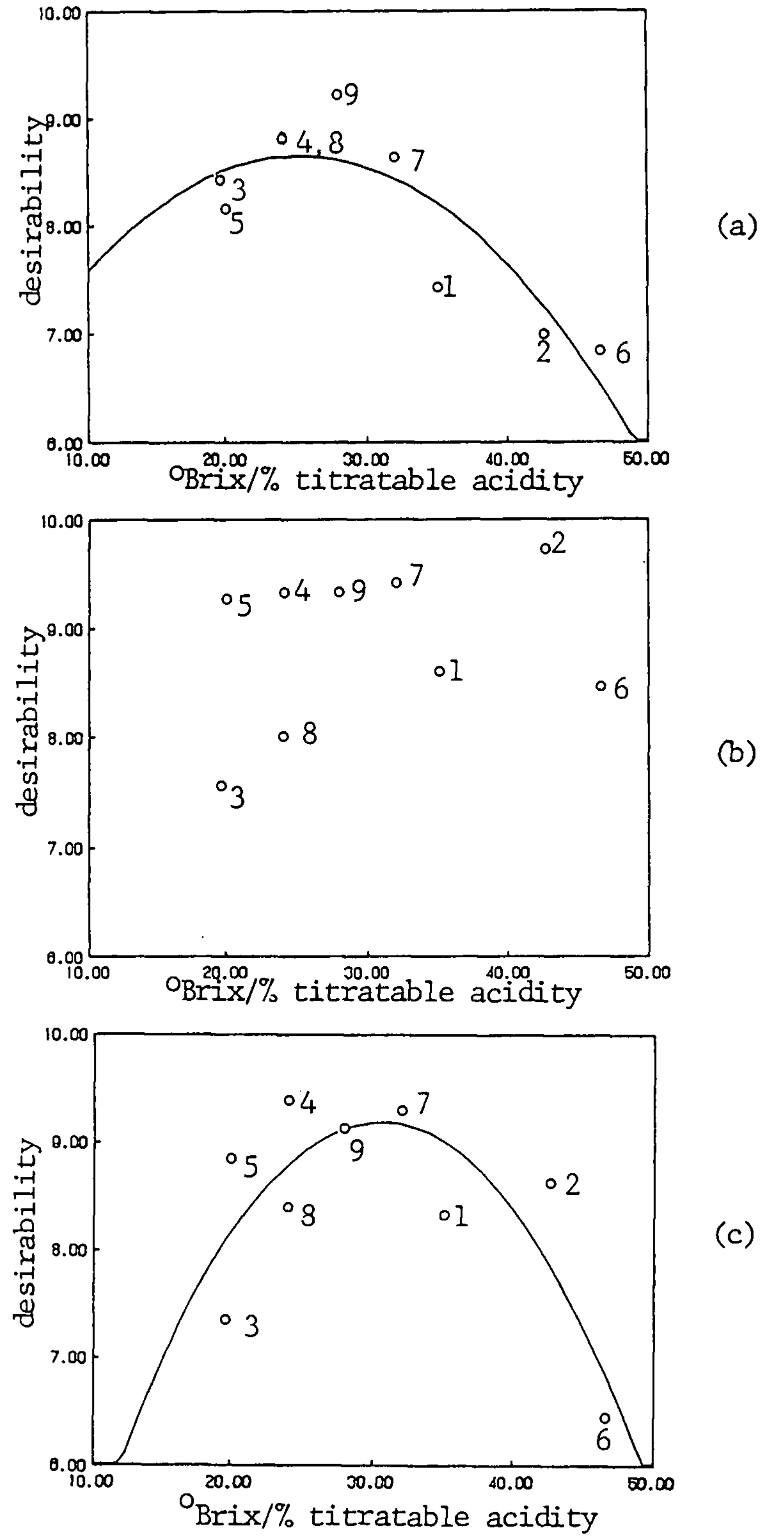


Fig. 18. Scatter plot of desirability versus °Brix/% titratable acidity for the 10% (a), 15% (b), and 20% (c) juice level drinks, respectively. Numbers (1-9) represent different formulations.

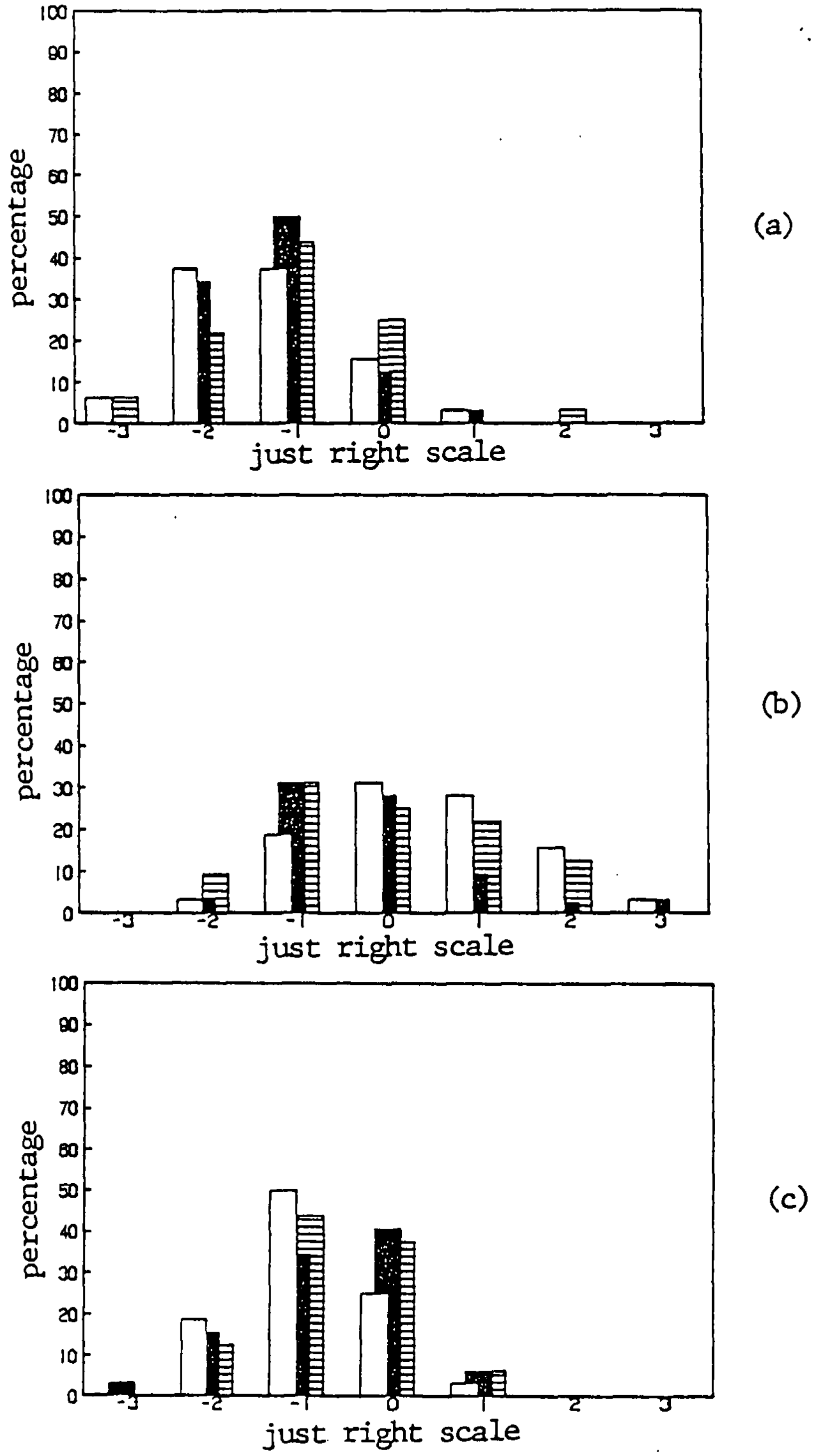


Fig. 19. Distribution of just-right ratings by the consumer panel for formula one for blackberry flavor (a), sweetness (b), and sourness (c) intensity for the 10% juice level (□), 15% juice level (■), and 20% juice level (▤), respectively.

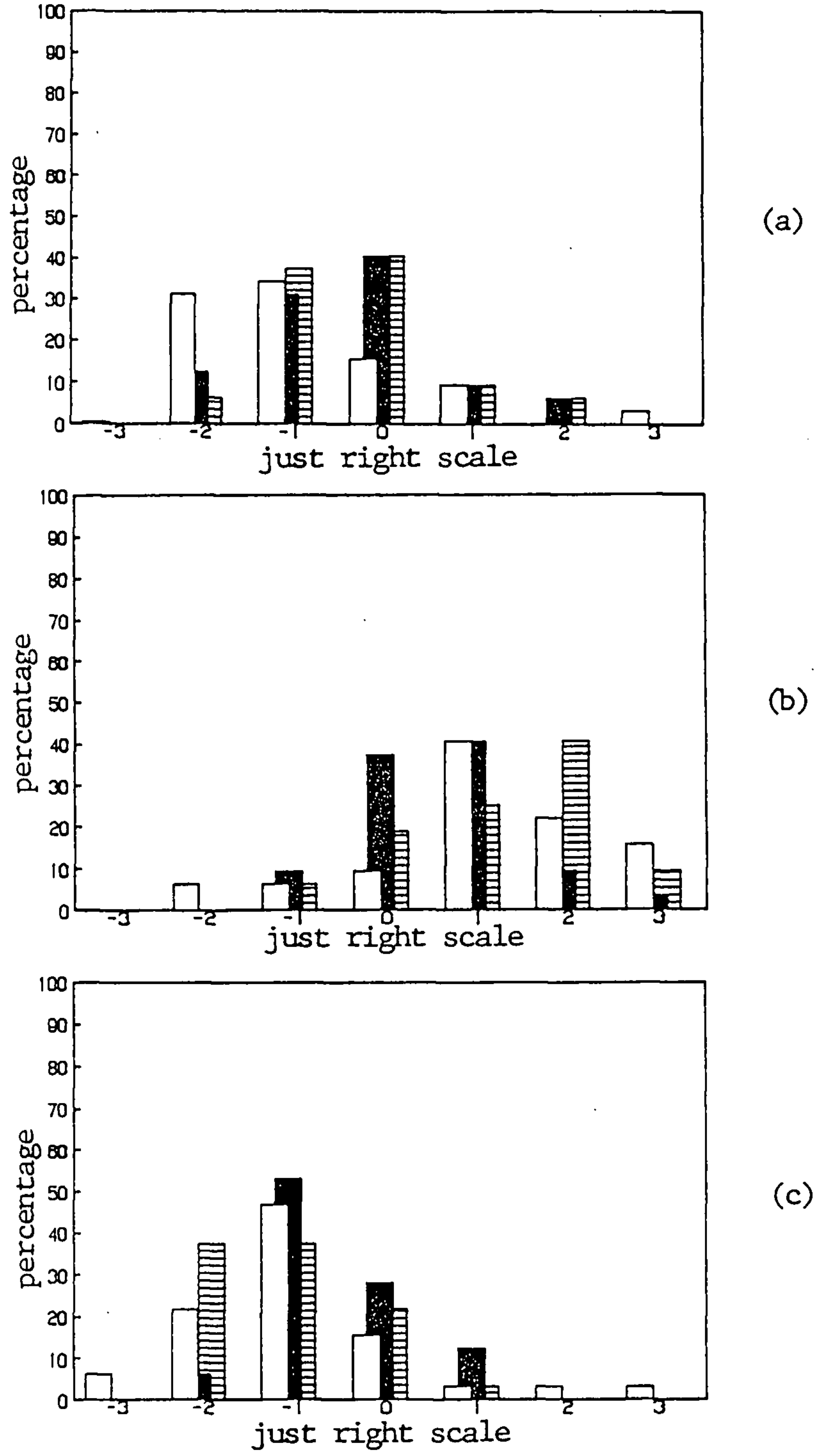


Fig. 20. Distribution of just-right ratings by the consumer panel for formula two for blackberry flavor (a), sweetness (b), and sourness (c) intensity for the 10% juice level (□), 15% juice level (■), and 20% juice level (▤), respectively.

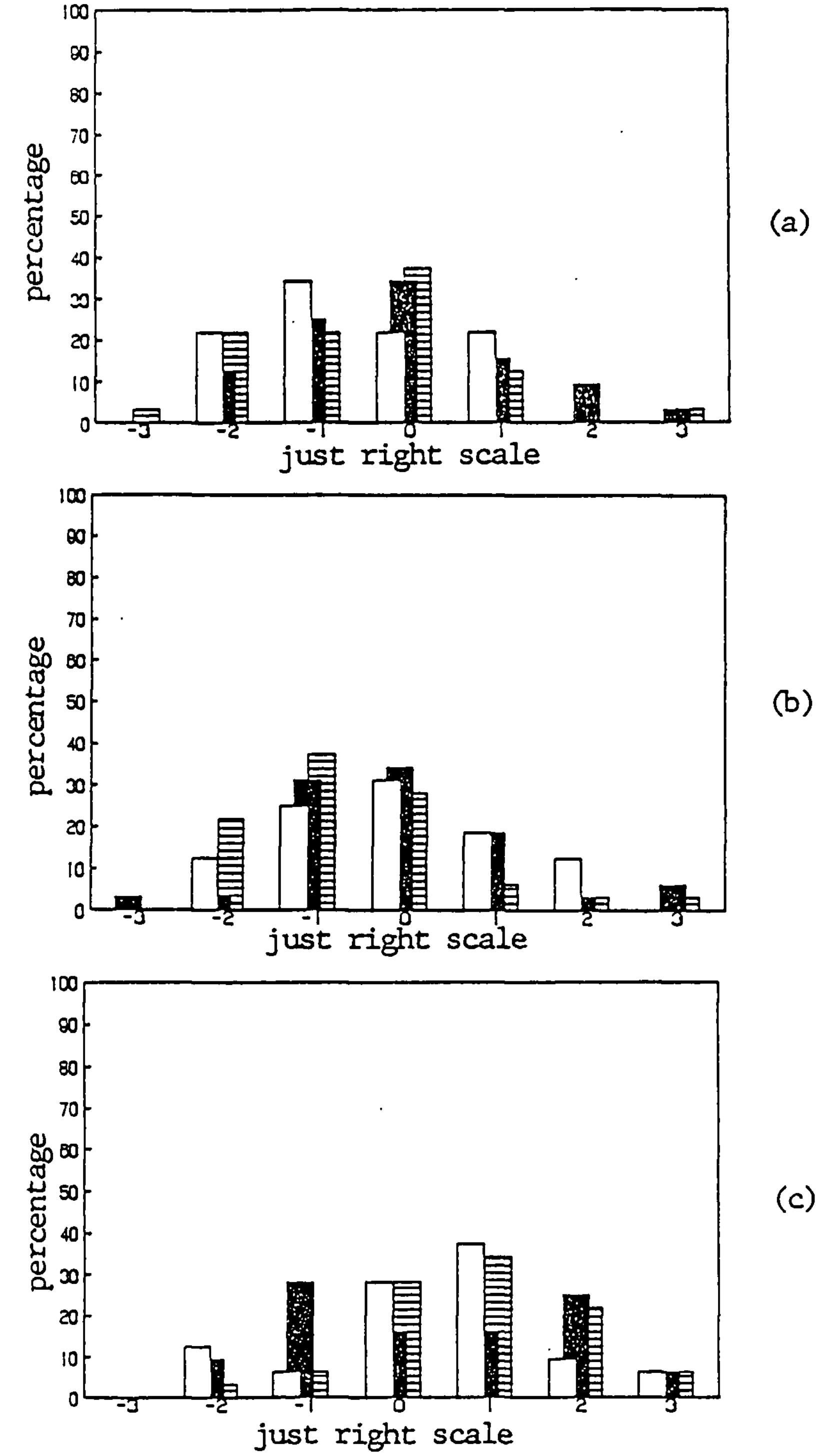


Fig. 21. Distribution of just-right ratings by the consumer panel for formula three for blackberry flavor (a), sweetness (b), and sourness (c) intensity for the 10% juice level (□), 15% juice level (■), and 20% juice level (⊟), respectively.

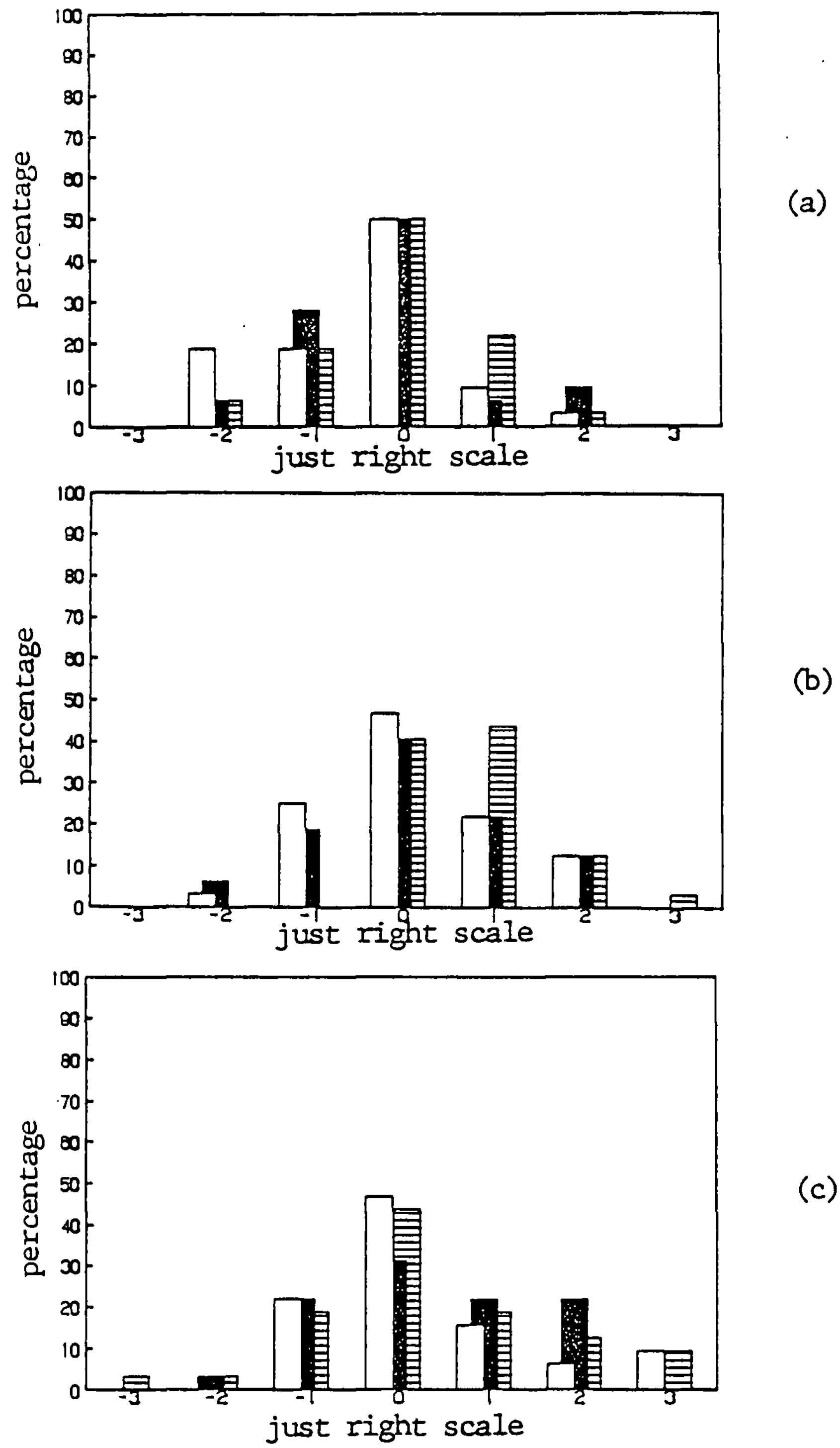


Fig. 22. Distribution of just-right ratings by the consumer panel for formula four for blackberry flavor (a), sweetness (b), and sourness (c) intensity for the 10% juice level (□), 15% juice level (■), and 20% juice level (▤), respectively.

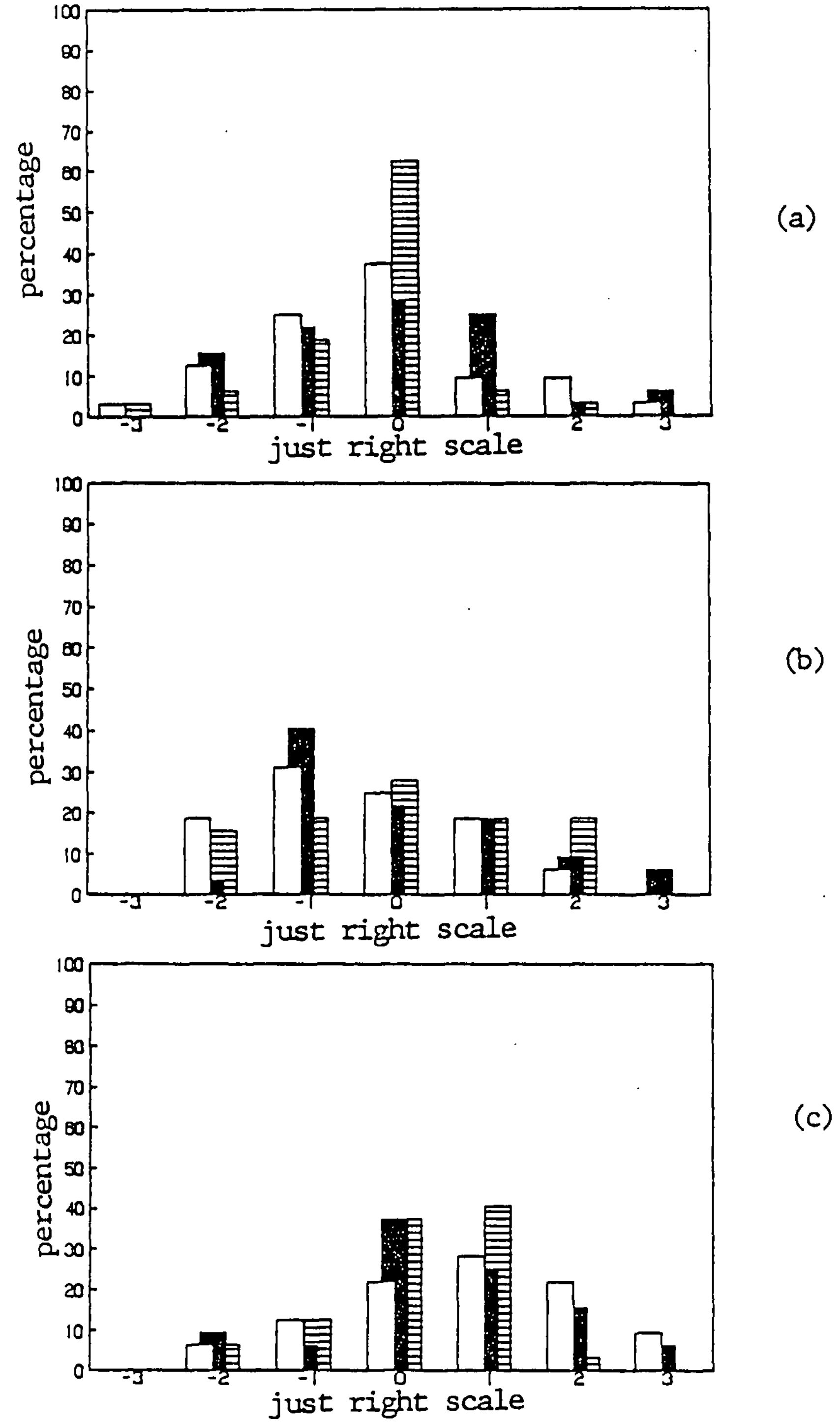
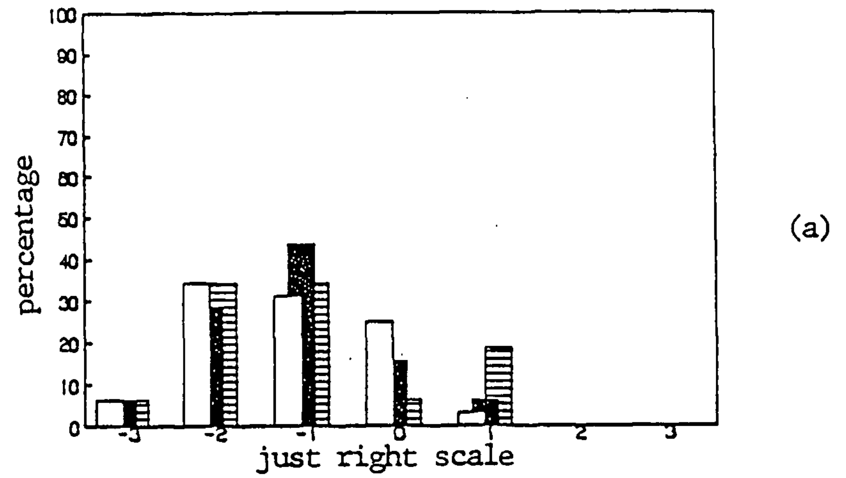
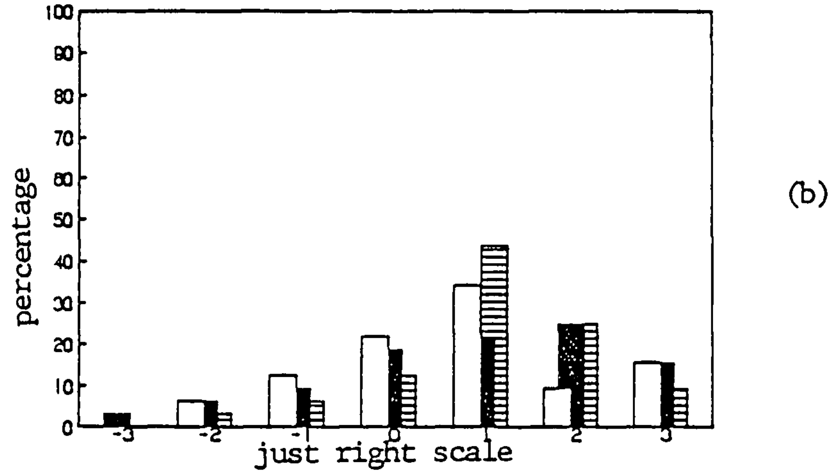


Fig. 23. Distribution of just-right ratings by the consumer panel for formula five for blackberry flavor (a), sweetness (b), and sourness (c) intensity for the 10% juice level (□), 15% juice level (■), and 20% juice level (▤), respectively.





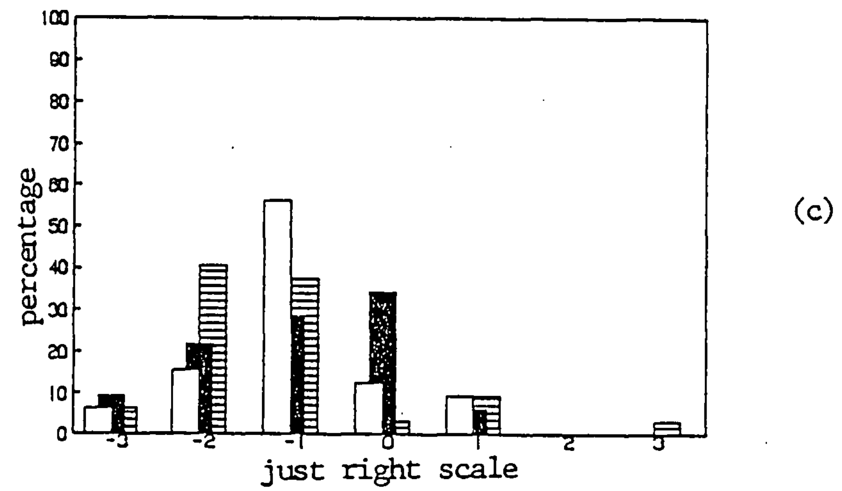


Fig. 24. Distribution of just-right ratings by the consumer panel for formula six for blackberry flavor (a), sweetness (b), and sourness (c) intensity for the 10% juice level (□), 15% juice level (■), and 20% juice level (▤), respectively.

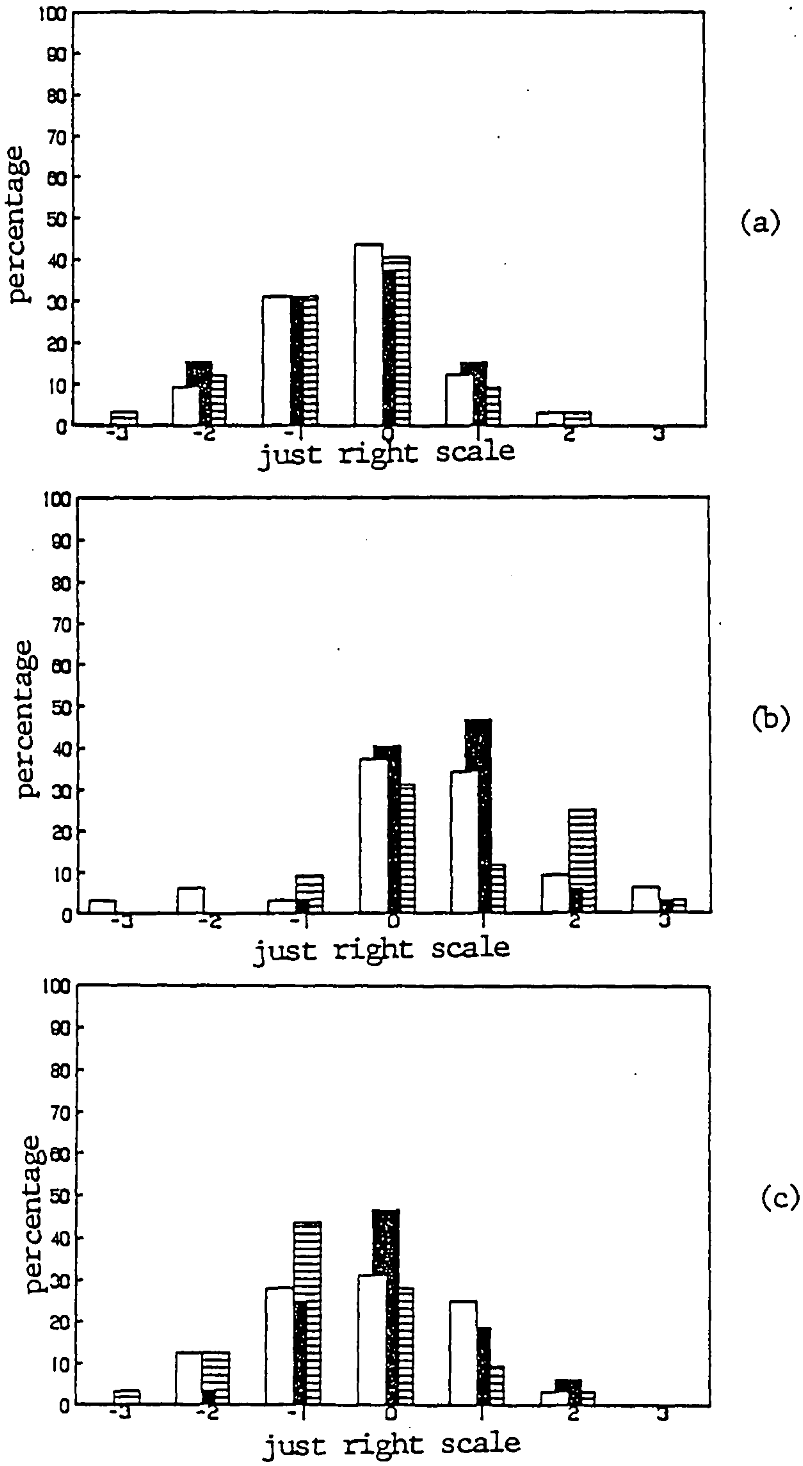


Fig. 25. Distribution of just-right ratings by the consumer panel for formula seven for blackberry flavor (a), sweetness (b), and sourness (c) intensity for the 10% juice level (□), 15% juice level (■), and 20% juice level (▤), respectively.

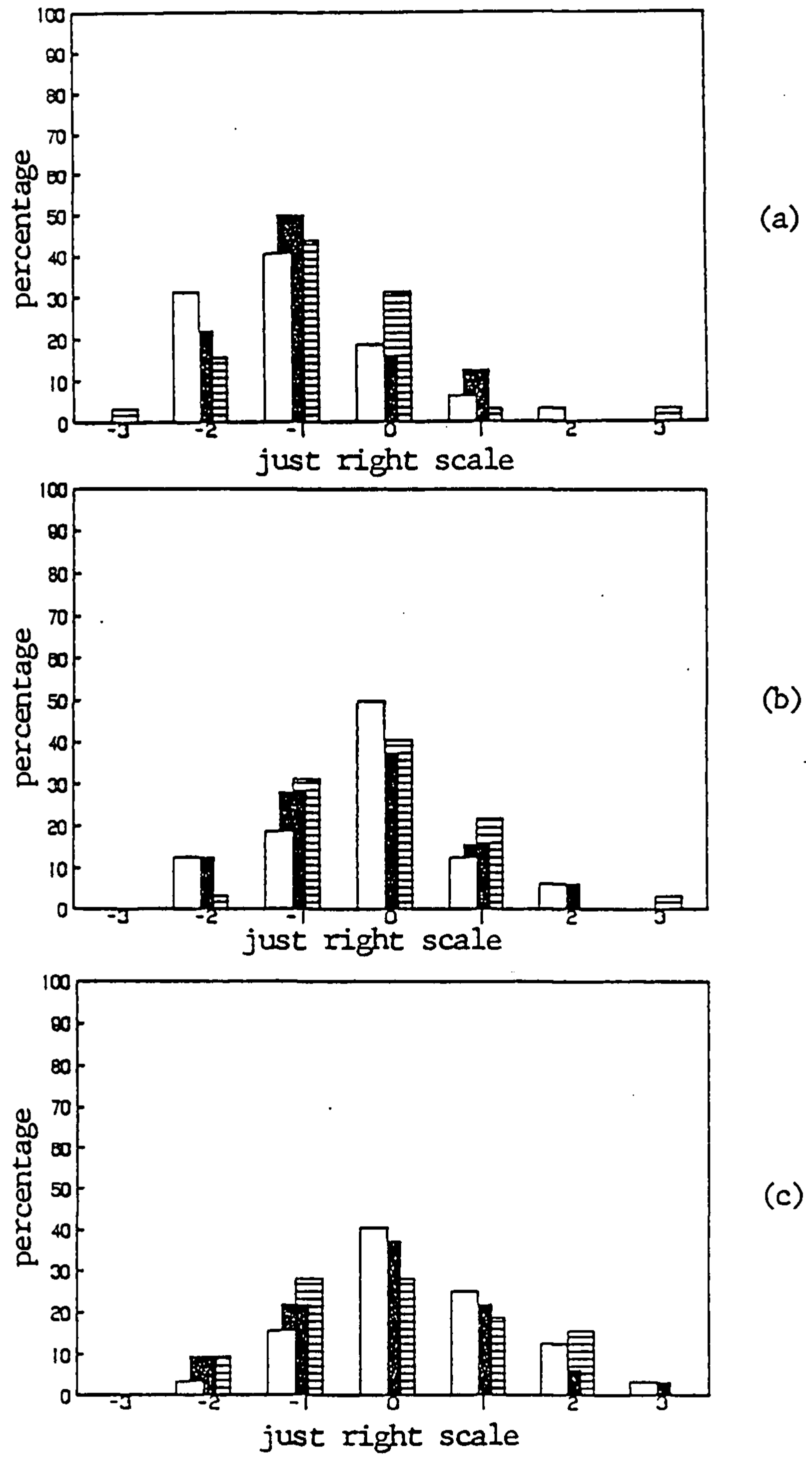


Fig. 26. Distribution of just-right ratings by the consumer panel for formula eight for blackberry flavor (a), sweetness (b), and sourness (c) intensity for the 10% juice level (□), 15% juice level (■), and 20% juice level (▤), respectively.

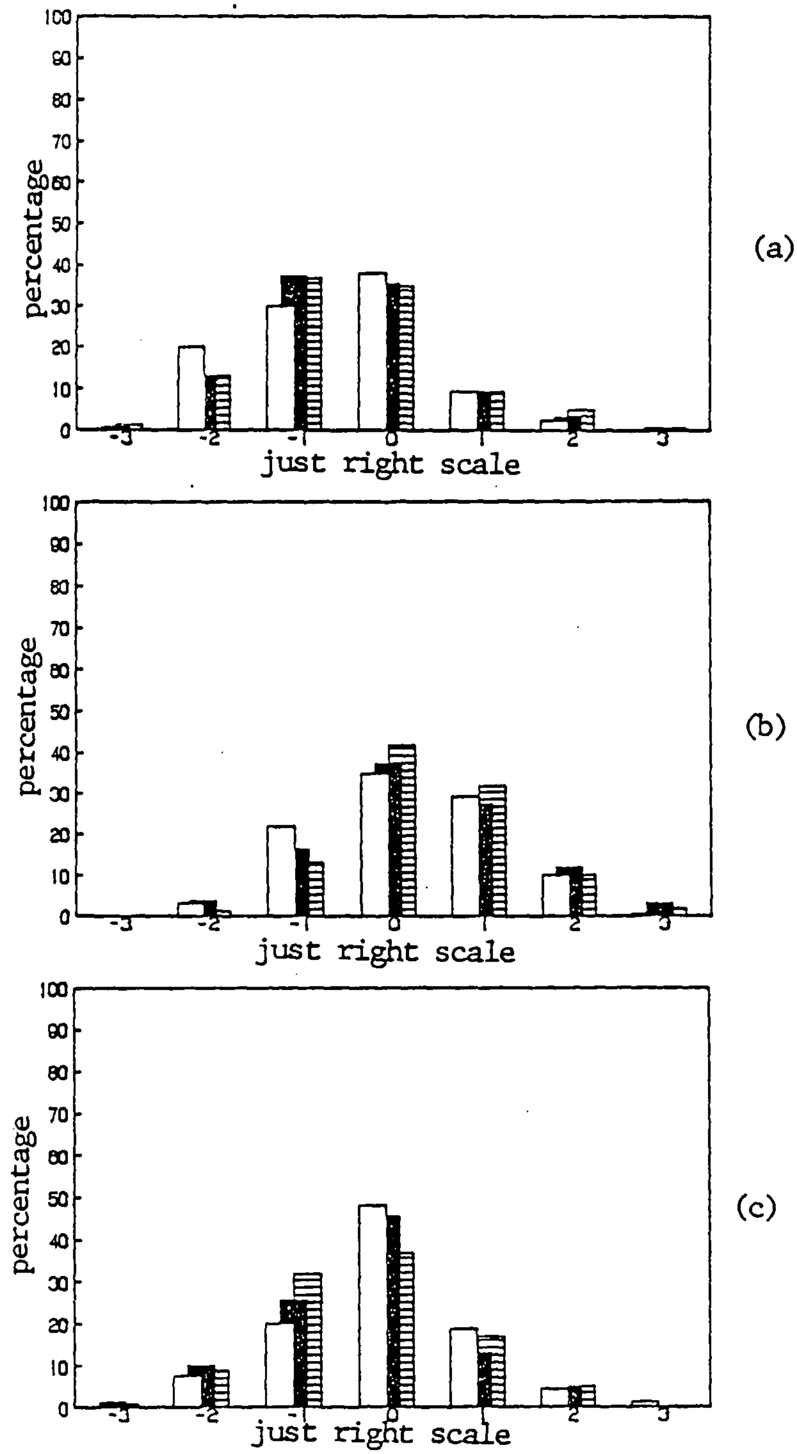


Fig. 27. Distribution of just-right ratings by the consumer panel for formula nine for blackberry flavor (a), sweetness (b), and sourness (c) intensity for the 10% juice level (□), 15% juice level (■), and 20% juice level (▤), respectively.

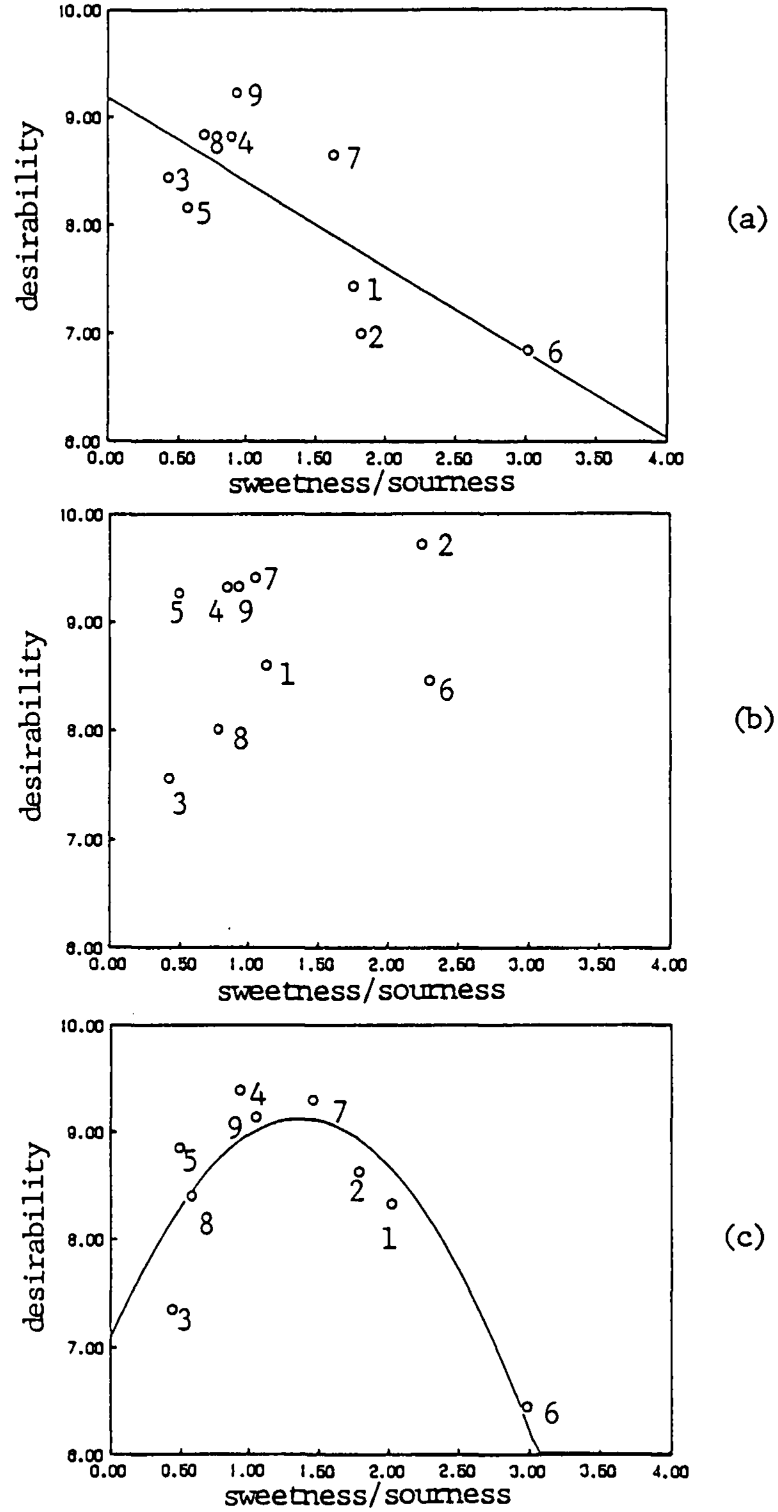


Fig. 28. Scatter plot of desirability versus sweetness/sourness acidity for the 10% (a), 15% (b), and 20% (c) juice level drinks, respectively. Numbers (1-9) represent different formulations.

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APPENDICES

Appendix 1. The ballot used for the trained panel.

NAME ____________________

DATE __________ SAMPLE NO.___

These are two sets of four samples of blackberry juice drink. Taste the samples starting from the left. Rate each sample for all attributes listed, and mark the line at a point appropriate to the extent of your perception.

BLACK BERRY FLAVOR:

|____|

None Extremely Strong

SWEETNESS:

|____|

None Extremely Strong

SOURNESS:

|____|

None Extremely Strong

COMMENTS: ____

____

Appendix 2. The ballot used for the consumer panel.

NAME:________________DATE:__________

There are four samples of blackberry drink. Taste the sample on the left and evaluate it for overall desirability, blackberry flavor, sweetness and sourness. Then evaluate the next sample for all attributes. Be sure to evaluate all four samples. Thank you.

SAMPLE # ______

OVERALL DESIRABILITY

dislike extremely	neither like nor dislike	like extremely
|___________________	|___________________	|

FLAVOR LEVEL	SWEETNESS	SOURNESS
___extremely too strong	___extremely too sweet	___extremely too sour
___moderately too strong	___moderately too sweet	___moderately too sour
___slightly too strong	___slightly too sweet	___slightly too sour
___just right	___just right	___just right
___slightly weak	___slightly not sweet enough	___slightly not sour enough
___moderately weak	___moderately not sweet enough	___moderately not sour enough
___extremely weak	___extremely not sweet enough	___extremely not sour enough

SAMPLE # _____

OVERALL DESIRABILITY

dislike extremely	neither like nor dislike	like extremely
|___________________	|___________________	|

FLAVOR LEVEL	SWEETNESS	SOURNESS
___extremely too strong	___extremely too sweet	___extremely too sour
___moderately too strong	___moderately too sweet	___moderately too sour
___slightly too strong	___slightly too sweet	___slightly too sour
___just right	___just right	___just right
___slightly weak	___slightly not sweet enough	___slightly not sour enough
___moderately weak	___moderately not sweet enough	___moderately not sour enough
___extremely weak	___extremely not sweet enough	___extremely not sour enough

Appendix 2 (cont.)

SAMPLE # ______

OVERALL DESIRABILITY

dislike extremely	neither like nor dislike	like extremely

FLAVOR LEVEL	SWEETNESS	SOURNESS
___extremely too strong	___extremely too sweet	___extremely too sour
___moderately too strong	___moderately too sweet	___moderately too sour
___slightly too strong	___slightly too sweet	___slightly too sour
___just right	___just right	___just right
___slightly weak	___slightly not sweet enough	___slightly not sour enough
___moderately weak	___moderately not sweet enough	___moderately not sour enough
___extremely weak	___extremely not sweet enough	___extremely not sour enough

SAMPLE # _____

OVERALL DESIRABILITY

dislike extremely	neither like nor dislike	like extremely

FLAVOR LEVEL	SWEETNESS	SOURNESS
___extremely too strong	___extremely too sweet	___extremely too sour
___moderately too strong	___moderately too sweet	___moderately too sour
___slightly too strong	___slightly too sweet	___slightly too sour
___just right	___just right	___just right
___slightly weak	___slightly not sweet enough	___slightly not sour enough
___moderately weak	___moderately not sweet enough	___moderately not sour enough
___extremely weak	___extremely not sweet enough	___extremely not sour enough