Sensory Evaluation of Mixtures of Sodium Cyclamate, Sucrose, and an Orange Aroma

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Mixtures of sucrose and sodium cyclamate (Na-cycl) were studied in the presence of orange aroma. Equisweet mixtures of the sweeteners were composed, which accounted for the observed synergistic effects between sucrose and Na-cycl. Sensory perceptions of combinations of these mixtures and an orange aroma were further described by quantitative descriptive analysis (QDA) to study possible interactive effects between the sweeteners and the orange aroma. Flavor profiles of a 100% sucrose solution and a 100% Na-cycl solution, both in the absence of orange aroma, significantly differed for the attributes chemical and aftertaste. Addition of orange aroma provided the solutions with a more distinct flavor and leveled out differences observed between sucrose and Na-cycl solutions. Further comments on the attribute aftertaste showed similar terms for the different solutions; orange, chemical, and mint were most often mentioned for solutions containing the orange aroma. The aftertaste of solutions containing relatively more Na-cycl was mainly described as bitter.

Keywords: *Sensory evaluation; sodium cyclamate; sucrose; orange aroma; interactions*

INTRODUCTION

Equisweet mixtures of sweeteners can be used as a basis for studying sweetness–flavor interactions. In previous experiments equisweet mixtures of maltitol or aspartame, sucrose, and an orange aroma were formulated with the help of Beidler's mixture equation (Nahon et al., 1998). A quantitative descriptive analysis (QDA) of the solutions did not reveal interactions between the sweeteners and the orange aroma. Mixtures of sweeteners showing synergy might affect the flavor profiles of these solutions (Nahon et al., 1996). Literature data showed that mixtures of sucrose and Na-cycl give positive synergy, and thus this mixture would be interesting to study.

Synergy between sucrose and cyclamate has been described before by Yamaguchi et al. (1970b), Hoppe (1981), Frank et al. (1989), and Portmann and Kilcast (1996b). The latter two determined a significant synergy; Frank et al. (1989) specified this synergy to be 15%. Hoppe (1981), on the contrary, reported a hindering between sucrose and Na-cycl, which would suggest a competition between sweetener molecules for receptor sites and thus an absence of synergy.

Showing synergy means that Beidler's mixture equation cannot be used to compose equisweet mixtures of the sweeteners sucrose and Na-cycl. A different approach has been chosen to equal their sweetness to the level of a 10 w/v % sucrose solution [denoted as 10% sucrose equivalent value (SEV)]. Several authors reported quite different SEVs for Na-cycl (Table 1). The background of the panelists (e.g., age, food preferences) might account for different judgments in sensory evaluation.

The results obtained with mixtures of sucrose and maltitol or aspartame showed that sucrose fits in the linear equation of Beidler (Nahon et al., 1998). Up to a concentration of 10 w/v % sucrose, the concentration of and response to this bulk sweetener are linearly related. The contribution of sucrose to the mixtures was thus fixed according to the chosen ratios. The next step was addition of Na-cycl until a sweetness equal to 10% SEV was reached.

Mixtures of sucrose and Na-cycl equisweet at 10% SEV were composed. QDA was used to find possible interactive effects between an orange aroma and mixtures of both sweeteners. The composition of the mixture solutions as well as the concentration of orange aroma was varied. The overall perception of the solutions was reflected in flavor profiles presenting attributes and their magnitudes. Faurion et al. (1980) and DuBois and Lee (1983) both described similarities between sucrose and Na-cycl in multidimensional analysis and in temporal sensory properties, respectively. Additionally, Hanger et al. (1996) found no differences between Na-cycl and sucrose for the attributes sweet (aftertaste), bitter (aftertaste), off-flavor, mouth coating, and drying. However, Portmann and Kilcast (1996a) reported a strong bitter flavor and bitter and metallic nonsweet aftertastes for Na-cycl. A caramel and burnt sugar flavor was also found, although these flavors are normally associated with nutritive sweeteners such as sucrose. Moskowitz and Klarman (1975) noticed that Na-cycl was rather pleasant at moderate concentrations but that this turned into unpleasantness at higher concentrations. In a lemonade product cyclamate was judged as sweet as and less tart than sucrose (Inglett et al., 1969).

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Table 1. SEVs for Sodium and Calcium Cyclamate, As Reported by Several Authors, the Standard Sucrose Reference, Details about the Preparation of the Solutions, and the Numbers of Subjects Used for the Determination

author(s)	year	10% SEV (w/v %)	sucrose ref (w/v %)	preparation/solutions	no. of subjects
DuBois and Lee	1983	0.5	10	Na-cycl	12
Faurion et al.	1980	0.35	9.6	frozen samples, Na-cycl	9
Frank et al.	1989	0.25	8.6	24 h before, Na-cycl	18−20
Hanger et al.	1996	0.11	4	fresh daily, Na-cycl	25
Hoppe	1981	0.6	10.4	Na-cycl	
Ketelsen et al.	1993	0.42	9	Ca-cycl	±30
Larson-Powers and Pangborn	1978a	0.86	10	16 h before, Ca-cycl	13
Portmann and Kilcast	1996a	0.44	10	24 h before, Na-cycl	12
Redlinger and Setser	1987	0.14	5	2.5 h before, Ca-cycl	7
Yamaguchi et al.	1970a	0.2	5.84	Na-cycl	100

In this study, mixtures of sucrose and Na-cycl equisweet at 10% SEV were composed and interactive effects between both sweeteners and an orange aroma were studied by QDA.

MATERIALS AND METHODS

Sensory evaluation was used to determine relative sweetnesses and to perform descriptive analyses. Whereas stimuli and subjects were the same in both cases, the methods (10% SEV determinations and QDA) are described separately.

Stimuli. Analogous with earlier experiments (Nahon et al., 1998), the stimuli were solutions of sucrose (CSM Suiker BV, Amsterdam, The Netherlands) and of Na-cycl (Flevo Chemie BV, Harderwijk, The Netherlands) and mixtures of these two substances in demineralized water. Nine sucrose/Na-cycl ratios (100/0, 90/10, 75/25, 60/40, 50/50, 40/60, 25/75, 10/90, and 0/100) were chosen to study possible interactive effects between sweeteners and aroma compounds. The pH of these solutions was measured with a Metrohm (Herisau, Switzerland) pH-meter. The overall sweetness of each mixture had to meet with a constant perceived taste intensity of 10% SEV. The standard stimulus for the SEV determinations was a 10 w/v % sucrose solution.

Solutions of sucrose, Na-cycl, acesulfame-K (Hoechst, Amsterdam, The Netherlands), orange aroma, and octanal (Merck, Hohenbrunnen, Germany) were used to generate attributes for the QDA. The standard stimuli "not sweet" and "very sweet" used in this analysis consisted of 0 and 16 w/v % sucrose, respectively. The orange aroma added to evaluate interactive effects was a sample of the watery vapor phase of stripped orange juice (Cargill juice division, Amsterdam, NL). It was used in concentrations of 0, 15, and 30 g/L.

All solutions were prepared at least 24 h before evaluation and stored at 4 °C overnight. In all evaluations, a stimulus consisted of 15 mL of solution. These stimuli were presented in a glass jar, covered by a plastic lid and aluminum foil to prevent interactions between the plastic and the orange aroma. The stimuli were presented to the panel at room temperature (22 °C).

Subjects. The panel for both sensory evaluations (at least 18 subjects) was chosen from a pool of 25 paid subjects (7 men and 18 women), ranging in age from 19 to 26 years. These subjects were selected and trained for the two experiments. Most subjects were students of Wageningen Agricultural University, some of them having prior experience of psychophysical experiments. Informed consents were obtained from the subjects, and the study was approved by the Medical Ethical Commission of Wageningen Agricultural University. Subjects were instructed to taste according to the sip-and-spit method, the time intervals between stimuli being kept at 60 s. After tasting of a solution, the subjects neutralized their mouths with water and crackers. Information from the survey was gathered by a computer interactive interviewing system (Ci2 system, Sawtooth Software Inc., Ketchum, ID).

SEV Determinations. Equisweet mixtures of the sweeteners sucrose and Na-cycl were composed by fixing the contribution of sucrose to the mixtures, according to the chosen ratios. Na-cycl was added until a sweetness of 10% SEV was reached (the partial SEV of Na-cycl). The extent of this addition was determined using the method of constant stimuli (Guilford, 1954) and weighted linear regression analysis (Bock and Jones, 1968). The panel was presented the standard stimulus, which is the 10 w/v % sucrose solution, and seven comparison stimuli. These consist of a fixed amount of sucrose and amounts of Na-cycl that vary exponentially near the expected partial SEV for Na-cycl. The determination of this partial SEV further follows the method as described by De Graaf and Frijters (1986). At least 252 datapoints were used for the determination of the composition of one ratio mixture (correlation coefficients of weighted linear regressions > 0.91). This method was then repeated for all nine ratio mixtures, which provides the composition of mixtures matching a 10% SEV.

Table 2. Mixtures of Sucrose and Sodium Cyclamate Matching a Sweetness of 10% SEV, Concentrations of Sucrose and Sodium Cyclamate, and pH of the Solutions

mixture ratio sucrose/Na-cycl	sucrose (w/v %)	Na-cycl (w/v %)	pH
100/0	10	0	6.5
90/10	9	0.015	6.2
75/25	7.5	0.043	6.5
60/40	6	0.086	6.0
50/50	5	0.111	6.0
40/60	4	0.140	6.2
25/75	2.5	0.236	5.9
10/90	1	0.335	6.0
0/100	0	0.443	5.9

Table 3. Attributes Describing the Flavor of Several Solutions Containing Sucrose (10 w/v %), Sodium Cyclamate (0.44 w/v %), Acesulfame-K (0.087 w/v %), Orange Aroma (15 g/L), and/or Octanal (0.05 g/L)

sweet	sharp	mint
orange	chemical	musty
bitter	fruity	aftertaste
sour	watery	

QDA. The solutions containing nine different combinations of sucrose and Na-cycl matching a sweetness of 10% SEV (Table 2) and three concentrations of orange aroma (0, 15, and 30 g/L) were evaluated by QDA. For this analysis, the subjects generated flavor attributes with the help of several solutions, which were ranked and clustered in consultation with the panel (Table 3). The panel was calibrated by tasting sucrose references of 0 and 16 w/v %, which were the anchors of the visual analogue scale for sweetness. Similar scales for other attributes were not anchored. The intensities of the attributes were marked on a 120 mm visual analogue scale (maximum score = 50) on a portable computer screen. Stimuli were presented randomly to the subjects, and subjects were asked to comment on aftertastes. To monitor the use of the scales, 5 and 12.5 w/v % sucrose solutions were evaluated as well. These solutions were randomly given with the other solutions to be evaluated.

Sensory data were subjected to Student's t tests to determine significant differences between solutions. A significance level of $P < 0.01$ was used for sweetness (anchored scale), and $P < 0.05$ was used for the other attributes.

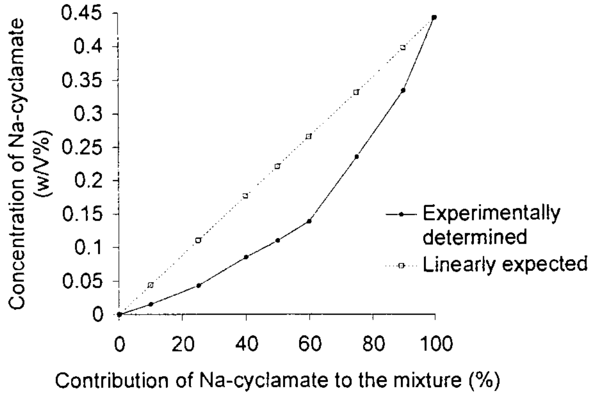

Figure 1. Concentration of Na-cycl (w/v %) in the mixture, as a function of the contribution of Na-cycl (%) to the mixture.

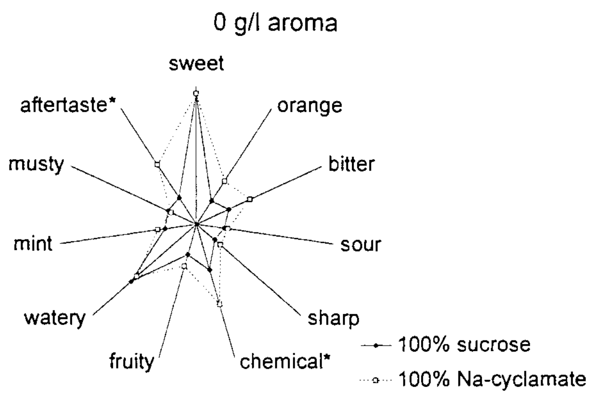

Figure 2. Spider web diagram representing the mean scores for sensory attributes of a sucrose and a Na-cycl solution at 10% SEV (in the absence of orange aroma): * = significant differences ($P < 0.01$ for sweetness, $P < 0.05$ for other attributes).

RESULTS

Figure 1 presents the results of the SEV determinations in comparison with linear expectations. The concentration of Na-cycl necessary to obtain equisweet mixtures at 10% SEV is smaller than follows from linearity.

The pH values measured for the mixture solutions used in the QDA are reported in Table 2. The pH values for the solutions containing orange aroma were in the same range. The results of the QDA show that the flavor profiles of a 100% sucrose solution compared with a 100% Na-cycl solution in the absence of orange aroma provide significant differences for the attributes chemical and aftertaste (Figure 2). A comparison between these two sweeteners in the presence of 30 g/L of orange aroma shows similar profiles (Figure 3); no significant differences were found. For the attribute sweet, the mean scores remain constant for each combination of sucrose and Na-cycl (Figure 4A). Figure 4B shows the mean scores for the attribute chemical. The contribution of orange aroma to the mean scores of this attribute is of a smaller magnitude for mixture solutions in which more Na-cycl is present. As in previous experiments (Nahon et al., 1998), standard deviations calculated for the attribute sweet were low for each combination of sucrose and Na-cycl. Again, it is difficult to find significant differences for the other attributes.

The terms used for the comments on the aftertastes of the different solutions did not differ from the attributes. However, solutions containing more Na-cycl tended to have more aftertaste, which is mainly described by the attribute bitter. For all three concentrations of orange aroma, subjects mentioned a bitter aftertaste for mixtures containing more Na-cycl (Figure 5). Solutions containing 15 or 30 g/L orange aroma provided stronger orange, chemical, and mint aftertastes than solutions without orange aroma.

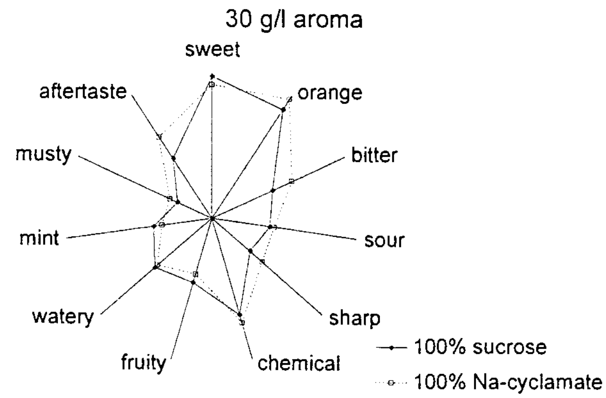

Figure 3. Spider web diagram representing the mean scores for sensory attributes of a sucrose and a Na-cycl solution at 10% SEV (in the presence of 30 g/L of orange aroma); no significant differences.

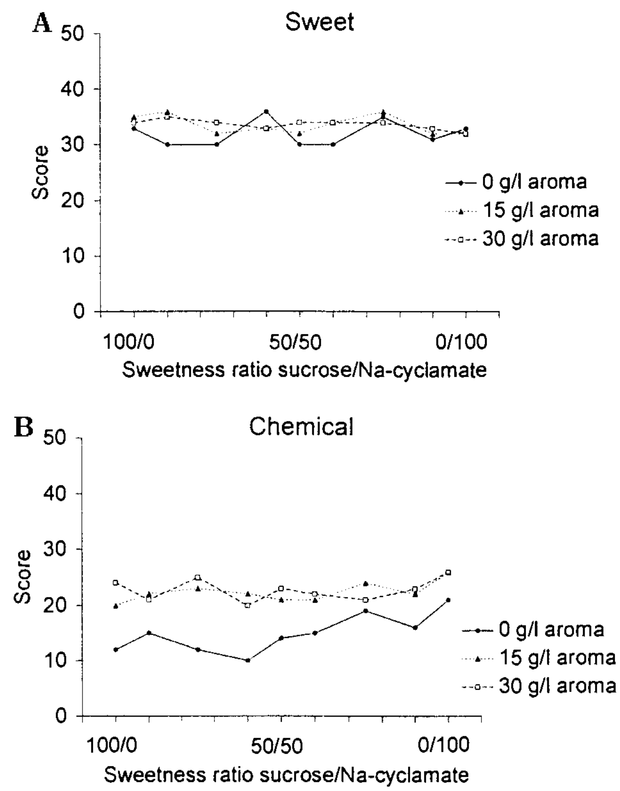

Figure 4. Mean scores for the sensory attributes sweetness (A) and chemical (B) for solutions containing mixtures of sucrose and Na-cycl. Three different concentrations of orange aroma (0, 15, and 30 g/L) were used.

DISCUSSION

The 10% SEV determined for Na-cycl in this study (0.44 w/v %) perfectly agrees with the value given by Portmann and Kilcast (1996a). However, most values reported in the literature were lower (Table 1). It seems to be very important to determine the SEVs related to the panel worked with, as we noticed before (Nahon et al., 1998). Figure 1 illustrates the difference between the linear expectations from Beidler's mixture equation

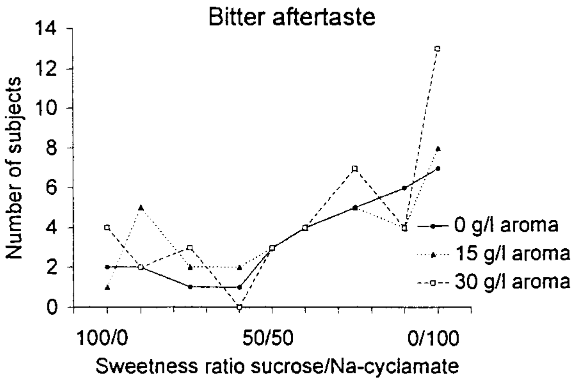

Figure 5. Number of subjects reporting a bitter aftertaste for solutions containing mixtures of sucrose and Na-cycl. Three different concentrations of orange aroma (0, 15, and 30 g/L) were used.

and the results of the present experiments. Upon composing equisweet mixtures of sucrose and Na-cycl, one would expect to add fractions from the 10% SEV of Na-cycl according to Beidler's method. This linearity was found before for mixtures of sucrose and maltitol or aspartame (Nahon et al., 1998). In case less Na-cycl is necessary than linearly expected, synergy has been found for these mixtures. Results from Table 2 and Figure 1 demonstrate a synergistic effect between sucrose and Na-cycl.

The synergy between sucrose and Na-cycl has been reported before by several authors. Yamaguchi et al. (1970b) found that a mixture of 3 w/v % sucrose and 0.2 w/v % Na-cycl was equisweet to a 9.2 w/v % sucrose solution. As can be seen from Table 2, these values are just between the values found for the 25/75 and 40/60 sucrose/Na-cycl mixtures. Redlinger and Setser (1987) determined a 0.140 w/v % calcium cyclamate (Ca-cycl) solution to be as sweet as a 5 w/v % sucrose solution. As this concentration of Ca-cycl is higher than the concentration necessary to obtain the 50/50 sucrose/Na-cycl mixture at 10% SEV, the presence of synergy between sucrose and (Na-)cycl was again confirmed. The synergy found by Portmann and Kilcast (1996b) was higher when less Na-cycl was present in the mixture. A look at their concentration−response relation for Na-cycl clarifies this effect, as this relation is negatively accelerated. Hoppe (1981) found a mixture of 75 g/L sucrose and 0.5 g/L Na-cycl to match the sweetness intensity of a 109.7 g/L sucrose solution. These values are similar to the ones reported in Table 2 for a 75/25 sucrose/Na-cycl mixture, which would suggest the presence of synergy. However, Hoppe (1981) ascribed these mixtures a hindering behavior. He used equations to quantify an expected mixture sweetness, which can then be compared with the experimentally determined mixture sweetness. The use of these equations introduces the reported hinderings, whereas a look at the actual concentrations in his Table 6 (Hoppe, 1981) indicates synergy. According to McBride (1988) a separate-sites model can account for the phenomenon of supplemental action. The sugars from a binary sugar system are transduced at independent receptor sites and then integrated in a common effector system to give a taste perception. Hutteau et al. (1998) showed that synergy can be correlated to an increase in water mobility and that an increased mobility of water molecules in the medium can be related to an increase in sweetness. They reported an increase in water mobility for sucrose/Na-cycl mixtures compared to sucrose. Synergistic effects observed, when two components are in mixture, are specific and depend on the compatibility of the hydration of each component and their influence on water structure.

Synergistic mixtures of sweeteners might show interactive effects with aroma compounds. The pH values measured for mixture solutions containing orange aroma were in the range of the pH values reported in Table 2. Apparently, the addition of orange aroma has no influence on the pH of the solutions. The results of the QDA are presented in Figures 2−5. Figure 2 shows a comparison between a sucrose solution and a Na-cycl solution at 10% SEV, both in the absence of orange aroma. In comparison with sucrose, the mean scores for Na-cycl are significantly higher for the attributes chemical and aftertaste. The observed significant difference for the attribute aftertaste is quite common for intense sweeteners. The results agree with the findings of Portmann and Kilcast (1996a). Other authors (Faurion et al., 1980; DuBois and Lee, 1983; Hanger et al., 1996) reported more similarities between sucrose and Na-cycl. In the descriptive analysis by Larson-Powers and Pangborn (1978b) samples containing Ca-cycl were characterized as "sweet-chemical" and "bitter"; they also had a cloying, "sticky-sweet", and "medicinal" aftertaste. Overall differences between Ca-cycl and sucrose were not found by Ketelsen et al. (1993), although Ca-cycl tends to have a longer aftertaste than sucrose. When a 100% sucrose and a 100% Na-cycl solution in the presence of 30 g/L of orange aroma (Figure 3) were compared, no significant differences were found. Apparently, the addition of orange aroma levels out differences mentioned for sucrose and Na-cycl.

Sweetnesses for all mixtures were kept at 10% SEV, as can be deduced from Figure 4A. The mean scores for the attribute sweet remain constant for each combination of sucrose and Na-cycl. The addition of orange aroma has no effect on these mean scores, as subjects accurately separate the scores on the different attributes, following the applied QDA method. The lines representing the mean scores for the attribute chemical for the three concentrations of orange aroma (Figure 4B) converge when more Na-cycl is present in the mixture. The addition of orange aroma accounts for this effect; the significant differences between sucrose and Na-cycl were leveled out. Comparison of Figures 2 and 3 illustrates the effect of an addition of orange aroma. For solutions containing Na-cycl only three attributes (orange, sour, and sharp) increase significantly, whereas for sucrose seven attributes change significantly (orange, sour, chemical, fruity, watery, mint, and aftertaste). When more sucrose is present in the mixtures, initial scores are relatively low and an addition of orange aroma substantially contributes to the mean scores. The addition of orange aroma then clearly gives the solutions a more distinct flavor. As Na-cycl gives higher mean scores on most of the attributes (Figure 2), an addition of orange aroma hardly increases these scores, according to the Weber ratio. For all mixture solutions, addition of orange aroma significantly increases the mean scores for the attribute orange. As expected, the addition of 30 g/L orange aroma did not double the mean scores obtained with 15 g/L of orange aroma (Nahon et al., 1998).

Comments on the aftertaste of the different solutions show that the significantly higher scores of Na-cycl on this attribute (Figure 2) can be ascribed to a lingering bitterness. The bitter aftertaste mentioned for mixtures containing more Na-cycl appears especially for the sweetness ratios 25/75, 10/90, and 0/100 sucrose/Na-cycl (Figure 5). Time–intensity measurements by Larson-Powers and Pangborn (1978a) showed a greater sourness and a marked, persistent bitterness of Ca-cycl compared to sucrose. Hanger et al. (1996) and Portmann and Kilcast (1996a) reported bitter aftertastes as well. The mean scores for the attribute aftertaste decrease as soon as a slight amount of sucrose is present in the mixture. The presence of sucrose in the mixture solution might change the system in such a way that effects of Na-cycl are suppressed immediately. Addition of orange aroma increases the orange, chemical, and mint aftertastes of solutions.

In conclusion, it was shown that mixtures of sucrose and Na-cycl are synergistic. With the help of SEV determinations equisweet mixtures were composed, which form an optimal basis for the study of sweetener–flavor interactions. A QDA then showed a leveling effect of orange aroma for significant differences observed between sucrose and Na-cycl.

ABBREVIATIONS USED

SEV, sucrose equivalent value; QDA, quantitative descriptive analysis; Na-cycl, sodium cyclamate; Ca-cycl, calcium cyclamate.

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