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Descriptive sensory analysis and free sugar contents of chestnut cultivars grown in North America

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Abstract

BACKGROUND: Various chestnut (*Castanea*) species and cultivars are currently produced and marketed in North America including Peach, Qing, AU-Homestead, Eaton, Marrone di Castel del Rio, and Colossal. In spite of their availability in the marketplace, similarities in sensory characteristics of chestnuts, as well as their unique attributes, have not been explored. Therefore, the objectives of this study were to evaluate texture and flavor attributes of commonly grown chestnut cultivars using descriptive sensory analysis and to quantify their free sugar content by gas–liquid chromatography.

RESULTS: Twenty-three sensory terms were used for descriptive analysis of roasted chestnuts. All but two attributes (raw impression and fermented) were common to all chestnut cultivars. Peelability, initial firmness, dissolvability, and mustard, sweet, and sour flavors varied among cultivars. Sucrose, the predominant free sugar in chestnuts, was greatest in Colossal chestnuts from California, while those of Peach had the lowest content. Glucose, fructose and maltose were also present in chestnuts.

CONCLUSION: This study demonstrated that cultivars of various chestnut species share several common sensory attributes, but differ in intensity ratings of six descriptors. Of these attributes, sweetness has been associated with consumer acceptance and can be promoted in the marketplace.

Keywords: *Castanea*; flavor; peelability; roasting; sucrose

INTRODUCTION

Currently several different chestnut species and their hybrids are grown and marketed in North America.[1] For example, some of the Chinese chestnut (*Castanea mollissima* Bl.) cultivars cultivated in the midwestern region of the USA include Peach, Qing, and AU-Homestead. Marrone di Castel del Rio is a European chestnut (*C. sativa* Mill.) cultivar grown in California and Oregon. Other chestnuts available in the marketplace are considered hybrids of European and Japanese (*C. crenata* Sieb. & Zucc.) species (Colossal, Bouche de Betizac, and Marsol cultivars) or an interspecific hybrid of *C. mollissima* × (*crenata* × *dentata* Bork.) (Eaton cultivar). Most of the cultivars grown in North America are described as having a sweet flavor, but few other flavor or textural attributes have been described.[2]

In a 2002 Michigan (USA) qualitative survey, several chefs preferred fresh, in-shell chestnuts rather than peeled ones because they liked the taste and texture of the nut after roasting.[2] In another study, acceptance of European chestnut cultivars was highly associated with sweetness.[3] Roasting at 210 °C for 60 min did not decrease the starch, sucrose, fructose, or glucose content of the nuts. Volatile compounds, including several monoterpenes and numerous derivatives of butane, pentane, hexane, and heptane, were identified as important aromas in roasted European chestnuts.[4] An aroma profile of Marrone del Mugello chestnut (*C. sativa*) included sweet vanilla, hazelnut, almond, and fresh bread.[5] Other researchers identified 33 and 30 volatile compounds in roasted and boiled *C. mollissima* chestnuts, respectively.[6]

For *C. sativa* cultivars, attributes such as appearance, color, flavor, taste, texture, and absence of episperm intrusions of chestnuts were assessed in European studies.[3,7–9] Recently, Italian researchers evaluated 18 European chestnuts grown in the Aosta Valley for seed color, ease of peeling, aroma, firmness, elasticity, flouriness, sweet, salty, and bitter attributes.[10] However, intensities of specific sensory descriptors have not been quantified by descriptive analysis for any of the chestnut cultivars of various species grown in North America. Therefore, the objective of this study was to evaluate the texture and flavor attributes of chestnuts from cultivars grown in North America using descriptive sensory

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analysis and to determine their free sugar content, since sweetness is an important flavor for consumer acceptance.

MATERIALS AND METHODS

Sample collection

Chestnuts from three trees each of Peach, Qing, Eaton, AU-Homestead, and Colossal were harvested at the University of Missouri Horticulture and Agroforestry Research Center near New Franklin, Missouri, USA on 26 September 2010. Trees were selected based on similarity in tree age (14 years old), crop load, and location within the site. Immediately after harvest, chestnuts were washed, dried for 4 h, sealed in polyethylene bags, and stored at 4 °C until sensory characteristics were evaluated. Marrone di Castel del Rio chestnuts were provided by a commercial grower in Isleton, California, USA. Colossal chestnuts were also obtained from the same source in California and another producer in Owosso, Michigan on 6 October 2010 to assess site variation. These chestnuts were also washed and dried as previously described and shipped by overnight mail to the Sensory Analysis Center at Kansas State University, Manhattan, Kansas, USA.

Sensory analysis

A descriptive sensory analysis panel composed of six highly trained panelists (between the ages of 42 and 74) from the Sensory Analysis Center participated in this study. Each panelist had more than 120 h of descriptive analysis training and averaged more than 1500 h of testing experience on many different product categories, including black walnuts.[11] Descriptive terms were generated during three 1.5 h orientation sessions. During this time, attributes and references were determined and reviewed to ensure understanding of the terms. Each panelist was presented a selection of chestnut samples to taste and subsequently identify sensory characteristics that discriminated the samples. Panelists' understanding and ability to use the identified sensory characteristics were assessed during orientation sessions. Discrepancies regarding the understanding of terms were discussed and resolved during these sessions. The panel came to consensus on 23 attributes (Table 1) to describe the samples.

After orientation sessions were completed, panelists evaluated samples in a well-lit (natural and fluorescent lighting) room at 22 ± 1 °C and ∼55% relative humidity. All samples were evaluated in triplicate over six 1.5 h sessions. A randomized complete block design was used to determine the serving order of the samples for the panelists. Each of the attributes was evaluated using a 0- to 15-point intensity scale (0.0 = none to 15.0 = extreme) with 0.5-point increments (references provided for some scale points). Eight samples were presented to the panelists during each session. Before serving, chestnuts were cured for 3 days at 22 °C. The pericarp (i.e. outer shell of nuts) was scored uniformly with a knife and chestnuts were roasted in an oven at 204 °C for 25 min. Five chestnuts were then placed in styrofoam bowls and covered with a lid for 10 min before serving. Panelists were instructed to

Table 1. Descriptive terms and definitions used in the sensory analysis of chestnuts

Attribute	Definition
Tactile	
Peelability	Ease of peeling the shell and pellicle away from the nut
Texture	
Initial firmness	Force required to initially bite through one piece of nutmeat using the incisors
Dissolvability	Degree to which the sample dissolves or remains semisolid when manipulated against the roof of the mouth with the tongue after 7 chews
Flavor	
Nutty	Intensity of all nutty characteristics including sweet, oily, light brown, slightly musty and/or buttery, earthy, woody, astringent and bitter flavors
Hazelnut-like	Sweet, light brown, oil somewhat woody aromatic associated with hazelnuts
Almond-like	Sweet cherry pit-like nutty aromatic associated with almonds
Maple	Sweet aromatic characterized as caramelized, woody and slightly green
Brown	Rich, full aromatic with a degree of darkness generally associated with canned pinto beans
Toasted	A brown, baked aromatic impression
Buttery	Aromatics commonly associated with natural, fresh, slightly salted butter
Caramelized	Aromatic of a round, full-bodied, medium brown sugar
Raw	An unprocessed or an uncooked impression
Beany	Slightly brown musty/earthy, musty/dusty, slightly nutty and starchy aromatics associated with beans
Fermented	Sweet, slightly brown, overripe aromatics associated with fermented fruits, vegetables, or grains with yeasty notes
Mustard	Sweet, woody sour, vinegar-like, somewhat pungent, slightly horseradish-like aromatics associated with prepared mustard
Floral/fruity	Aromatics associated with flowers and non-citrus fruits
Musty/dusty	Aromatic associated with dry, brown soil
Musty/earthy	Aromatics of a damp basement or soil or decaying vegetation
Oily	Light aromatics associated with vegetable oil such as corn or soybean oil
Sweet	Basic taste associated with sucrose
Sour	Basic taste associated with citric acid
Bitter	Basic taste described as harsh with the taste simulated by solutions of caffeine
Astringent	Sensation of drying, drawing-up or puckering of any of the mouth surfaces

use at least three samples during evaluations. Distilled, deionized water and unsalted crackers were served as palate cleansers. A minimum break of 2 min was taken between each sample. Ratings were collected using Compusense *five* commuter (Version 4.6.702, Compusense Inc., Guelph, Ontario, Canada).

Free sugar analysis

Thirty chestnuts of each cultivar were roasted, pericarps were removed as previously described and ethanol extracts of homogenized samples were prepared for free sugar analysis. Fifty milliliters of 50% ethanol containing 3-*O*-methyl-glucose (5 mg) as an internal standard were added to 10 g of each chestnut sample and homogenized for 10 min at 4 °C in a blender. Following centrifugation at 252 × *g* for 5 min at 4 °C, triplicate unfiltered 1.0 mL aliquots were dried in Teflon-lined capped 13 × 100 mm culture tubes, *in vacuo*, for subsequent carbohydrate analyses.

To one set of tubes designated for neutral monosaccharides analysis as alditol acetates, 1.0 mL deionized water, 20 µL of 5% sodium carbonate and 1.0 mL sodium borohydride solution (0.5 mol L^{-1}) were added sequentially. Next, 150 µL of 50% acetic acid was added to each tube and after mixing the samples were dried *in vacuo*. Boric acid was removed by the sequential addition and evaporation of 3 × 100 mL dry methanol. For the acetylation of alditols, 1.0 mL pyridine and 2.0 mL acetic anhydride were added to each tube and heated at 75 °C for 60 min. Reactions were reduced to near dryness under a stream of dry nitrogen and then 1.5 mL of dichloromethane and 3.0 mL deionized water were added to each sample. Tubes were then centrifuged at 500 rpm for 1 min and the organic phases were transferred to 2.0 mL autosampler vials for gas–liquid chromatography (GLC) analysis.

For disaccharide analysis as per-*O*-trimethylsilyl ether derivatives, 100 µL dry pyridine, 150 µL trimethylsilylimidazole and 300 µL *N*,*O*-*bis*-trimethylsilyltrifluoroacetamide were added sequentially to samples under dry argon. After heating at 75 °C for 1 h, reaction mixtures were individually transferred to 2.0 mL autosampler vials for subsequent GLC analysis.

All carbohydrate analyses were performed on an Agilent Technologies, model 7890A, gas–liquid chromatograph (Lexington, MA, USA) equipped with dual flame ionization detectors. For the analysis of alditol acetates, a 30 m × 0.25 mm, fused-silica capillary column (Quadrex, New Haven, CT, USA) was used. The helium flow rate was 5 mL min^{-1} with 300 °C injector and detector temperatures. After 9 min at 200 °C, the oven temperature was programmed to 220 °C at 10 °C min^{-1}, held for 4 min, then ramped to 240 °C at 10 °C min^{-1}. For the analysis of disaccharides, a 10 m × 0.25 mm fused-silica column was used (Quadrex, New Haven, CT, USA). The helium flow rate was 5 mL min^{-1} with 310 °C injector and detector temperatures. After 1 min at 140 °C, the oven temperature was programmed to 280 °C at 10 °C min^{-1} and then held at this temperature for 2 min. All peak areas, retention times and integrations were recorded using EzChrom Elite software (Agilent, Lexington, MA, USA).

Data analysis

A statistical analysis was performed for each sensory attribute using SAS (version 9.2; SAS Institute, Cary, NC, USA). Analysis of variance (ANOVA) was conducted for each attribute with cultivar, replicate, and panelist, as well as all two-way interactions of these factors, using PROC GLM. Panelists were treated as a random effect and therefore replicate × treatment was used as the error term for both ANOVA and Fisher's protected least significant differences (LSD) at ($P \leq 0.05$). Principal components analysis (PCA) was conducted using the covariance matrix (data not standardized) and quatrimax rotation for ease of reading the biplot. Unscrambler® (version 9.8; Camo Software AS, Oslo, Norway) was used to perform the PCA. Free sugar data were also subjected to ANOVA and means were separated by Fisher's LSD tests at $P \leq 0.05$.

RESULTS AND DISCUSSION

Sensory attributes

Twenty-three sensory attributes were used to qualify and quantify the chestnut cultivars in this study, including three textural descriptors (peelability, initial firmness, and dissolvability) and 20 flavor attributes. Chestnut cultivars were characterized by a slight nutty flavor (5.4–6.0 mean intensity ratings). Slightly lower impressions of brown, toasted, and beany flavors were also perceived in chestnut samples (4.0–4.9 ratings). Lower, but detectable levels of hazelnut-like, almond-like, maple, buttery, caramelized, musty/dusty, musty/earthy, oily, sweet, sour, bitter, and astringent flavors (<3 ratings) were perceived. Mustard was present at a sensory threshold (≥1 rating) in only one sample and ratings for floral/fruity, raw impression, and fermented were very low (<1 rating). These results demonstrate that cultivars commonly grown in North America have a complex flavor profile. Previous sensory studies that included *C. sativa* cultivars have been limited to 2–11 attributes, with sweetness always included as a descriptor.[3,5,7,8,10] The additional descriptors identified in our study likely expand the generic attributes such as 'chestnut aroma', 'flavor', 'taste', and 'texture' used in previous reports. Also, the development of a formal lexicon with definitions for each attribute in the present study is an additional refinement of previous chestnut sensory research.

Results from this study also indicated that six sensory characteristics of the chestnuts varied significantly ($P \leq 0.05$) among cultivars (Table 2). AU-Homestead, Eaton, and Qing chestnuts had higher peelability ratings than all other cultivars. These cultivars, in addition to Colossal from Missouri and Peach, were also easier to peel than Colossal harvested in California. Initial firmness ratings of Colossal from Michigan and Missouri and Marrone di Castel del Rio chestnuts were lower than all other cultivars. Marrone di Castel del Rio chestnuts had a higher dissolvability rating than those of AU-Homestead, Colossal from California, Peach, and Qing.

Three flavor attributes differed significantly in intensity ratings among cultivars. Marrone di Castel del Rio chestnuts had a higher mustard intensity rating than those of all other cultivars. Marrone di Castel del Rio and Colossal from Michigan chestnuts were sweeter than those of Peach and Qing. AU-Homestead and Peach chestnuts had a higher sour intensity rating than Colossal chestnuts from Missouri.

In an earlier study, sensory criteria used for selecting suitable *C. sativa* cultivars for roasting included size, peelability, aroma, sweetness, and texture attributes.[3] For example, the chestnut cultivar Pinca had a sweet flavor and a high intensity rating for aroma and texture in an study conducted in Switzerland, but was judged unacceptable for use due to the difficulty in peeling.[3] Cultivars with a fine texture and melting quality in the mouth (i.e. high dissolvability ratings) were also considered commercially acceptable. Such standards have yet to be developed for cultivars grown in North America due to infancy of the industry.

Results from the PCA showed that the first two principal components (PC1 and PC2) accounted for 81% of the variation (Fig. 1). Peach chestnuts were characterized by bitterness, raw

Table 2. Mean sensory attribute intensity ratings for chestnut cultivars

Descriptor	AU Homestead	Colossal California	Colossal Michigan	Colossal Missouri	Eaton	Marrone di Castel del Rio	Peach	Qing	*P*-value
Peelability	14.86a	8.08d	9.36cd	11.67b	14.83a	8.72cd	10.28bc	14.83a	<0.0001
Initial firmness	7.00a	6.86a	5.81b	5.94b	7.33a	5.86b	7.08a	7.06a	0.0014
Dissolvability	6.50bc	6.39c	6.97ab	6.75abc	6.81abc	7.08a	6.36c	6.44c	0.0498
Nutty	5.75	5.78	5.92	6.03	5.72	5.58	5.42	5.58	0.2827
Hazelnut-like	1.92	1.94	2.19	2.06	2.06	1.61	1.69	1.94	0.3801
Almond-like	1.94	1.81	1.86	2.06	1.92	1.92	1.47	1.78	0.1599
Maple	1.61	1.78	1.94	1.92	1.72	1.50	1.50	1.56	0.5349
Brown	4.78	4.42	4.72	4.89	4.86	4.69	3.97	4.25	0.1676
Toasted	4.33	4.17	4.50	4.61	4.50	4.39	3.94	4.19	0.1648
Buttery	2.72	2.56	2.78	2.94	2.72	2.92	2.47	2.75	0.2428
Caramelized	2.36	2.53	2.72	3.14	3.17	2.42	2.11	2.72	0.4835
Raw impression	0.28	0.47	ND	0.06	0.17	0.11	0.61	0.58	0.1163
Beany	4.39	4.11	4.31	4.28	4.31	4.22	4.31	4.67	0.8564
Fermented	ND	0.14	ND	ND	0.25	ND	0.11	0.06	0.0650
Mustard	0.17b	0.33b	0.33b	0.58b	0.17b	1.58a	0.11b	0.31b	0.0498
Floral/fruity	0.44	0.39	0.61	0.67	0.64	0.44	0.33	0.33	0.8485
Musty/dusty	2.44	2.56	2.28	2.36	2.47	2.36	2.47	2.31	0.6193
Musty/earthy	1.89	2.19	2.00	2.17	2.28	2.22	2.39	2.36	0.6189
Oily	2.64	2.53	2.69	2.69	2.53	2.72	2.39	2.47	0.3261
Sweet	2.50bcd	2.64abcd	2.78ab	2.67abc	2.69abc	2.92a	2.36d	2.44cd	0.0266
Sour	1.92ab	1.72bc	1.72bc	1.64c	1.72bc	1.78bc	2.00a	1.78bc	0.0168
Bitter	2.39	2.44	2.19	2.42	2.31	2.25	2.89	2.42	0.0455
Astringent	1.75	1.75	1.75	1.86	1.81	1.89	1.92	1.86	0.1409

Values with different letters in a row are statistically significant at $P \leq 0.05$ by Fisher's least significant difference (LSD) test.
ND, not detected.

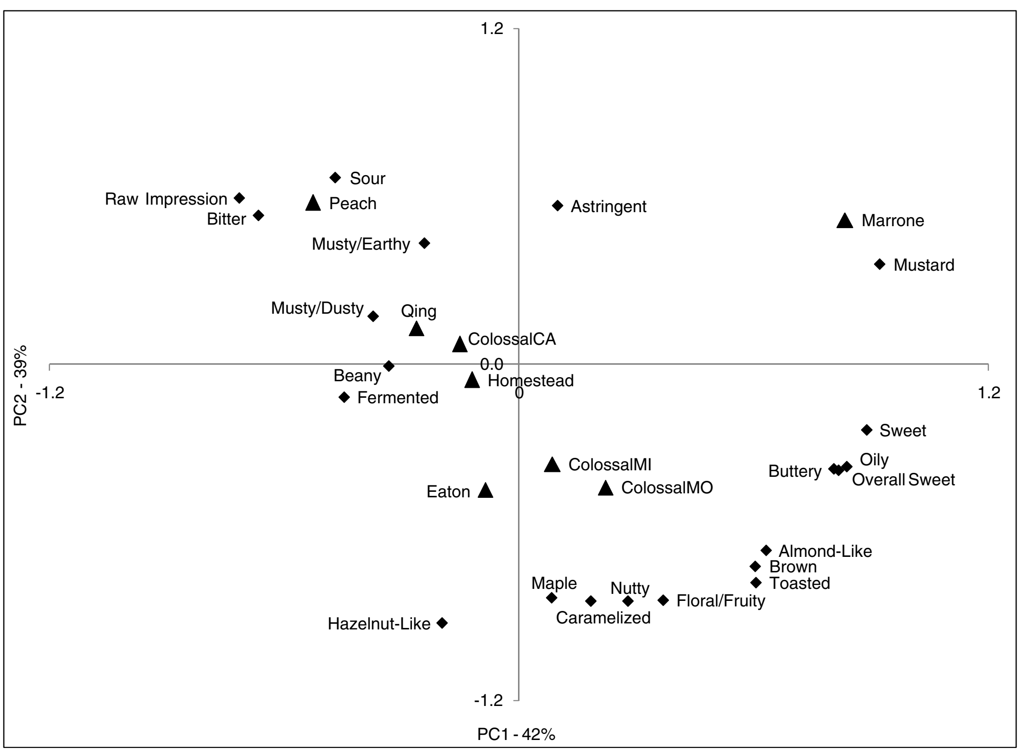

Figure 1. Principal components analysis biplot showing the relationship between chestnut samples and flavor attributes.

Table 3. Mean sucrose, glucose, and maltose content (g kg^{-1}) of chestnut cultivars

Free sugar	AU Homestead	Colossal California	Colossal Michigan	Colossal Missouri	Eaton	Marrone di Castel del Rio	Peach	Qing
Sucrose	87.0d	125.8a	114.5b	77.0de	76.2e	102.5c	58.8f	71.1e
Glucose	1.1c	1.9abc	2.3ab	1.3bc	0.8c	1.6bc	2.9a	1.1c
Fructose	1.0ab	0.2c	0.5bc	1.0ab	1.2a	0.1c	0.3c	0.6abc
Maltose	6.2a	1.1d	1.3d	2.1d	2.5cd	0.8d	5.7ab	4.0bc

Values with different letters in a row are statistically significant at $P \leq 0.05$ by Fisher's least significant difference (LSD) test.

impression, sourness, and musty/earthy (although not significant). Qing samples tended to have a high intensity of beany flavor. The perception of mustard flavor was greatest in Marrone di Castel del Rio chestnuts. Colossal chestnuts grown in California had higher raw and musty/dusty impression and generally had less maple, brown, toasted, buttery, caramelized, and floral/fruity flavor intensity as compared to Colossal samples grown in Michigan and Missouri. Eaton chestnuts tended to have high hazelnut-like notes, as well as those of Colossal from Michigan and Missouri.

The reason Colossal chestnuts from California were distinguished from those grown in Michigan and Missouri may be attributed to extremely warm temperatures before harvest. In Isleton, California the mean maximum daily temperature in August (no precipitation) and September was 32.8 °C (6.6 mm rainfall). In contrast, the mean maximum daily temperature where other Colossal chestnuts were grown was 25.4 and 16.8 °C in August and September, respectively, in Oswosso, Michigan and 27.6 and 24.7 °C, respectively, in New Franklin, Missouri. Precipitation at both locations was over 60 mm for each month. Thus the high temperatures before harvest may have altered the development of flavors, resulting in relatively lower ratings of maple, brown, toasted, buttery, caramelized, and floral/fruity flavors for Colossal chestnuts from California as compared to those samples from the other two cooler locations. While specific flavor attributes have not been previously identified for chestnuts under varying environmental conditions, climatic stress (high temperatures, solar radiation, and rainfall) has been associated with poor chestnut quality.[12] In other foods, heat-induced and 'sunlight' flavors have been documented.[13]

The mustard flavor may be related to undetected microorganisms under the pericarp or within other tissue, even though chestnuts with visible defects were discarded and post-harvest refrigeration was used to prevent spoilage. In other studies, microorganisms have been isolated from the pericarp surface and cotyledons (edible 'nut') of chestnuts.[14,15] In a Michigan survey of seven farms, the predominant microorganisms that negatively impacted fresh chestnuts included *Penicillium expansum, P. griseofulvum, P. chysogenum, Coniophora puteana, Acrosperia mirabilis, Botryosphaeria ribis, Sclerotinia sclerotorum, Botryotinia fuckeliana* (Anamorph *Botrytis cinerea*) and *Gibberella* sp. (Anamorph *Fusarium* sp.).[15] A post-harvest disinfectant treatment such as chlorination with sodium hypochlorite, sorbic, propionic or peracetic acid, natamycin, or ozonation can be used for long-term storage of chestnuts.[16] However, in this study, chestnuts were not disinfected to prevent the introduction of non-chestnut flavors.

Free sugar content of roasted chestnuts

Sucrose was the predominant sugar extracted from chestnut cultivars, with lower contents of glucose, fructose, and maltose, and only trace amounts of lactose and galactose detected (Table 3). Ribose, fucose, arabinose, and xylose were not detected. Colossal chestnuts from California and Michigan, and Marrone di Castel del Rio had the greatest sucrose content, while those of Peach had the lowest content. Differences in sucrose were more readily distinguished among cultivars by GLC analysis than by sensory intensity ratings of sweetness with sucrose used as a standard. For glucose, Colossal from Michigan and Peach chestnuts had the greatest content and AU-Homestead, Eaton, and Qing had the lowest amount. AU-Homestead, Colossal from Missouri, and Eaton chestnuts had more fructose than those of Colossal from California, Marrone di Castel del Rio, and Peach. For maltose, AU-Homestead had more of this sugar than any of the chestnut cultivars except Peach. In an earlier Swiss study, roasted *C. sativa* chestnut cultivars (Lüina, Pinca, Torción negro, Marrone di Cuneo, and Marigoule) had similar sucrose contents (93–156 g kg^{-1}) to those found in Marrone di Castel del Rio (also *C. sativa*) and Colossal from California in our study. However, other chestnut species and hybrids assayed in the present study had lower sucrose contents (58.8–87.0 g kg^{-1}) after roasting.[3] Cultivars grown in North America also had relatively low fructose contents (0.1–1.2 g kg^{-1}) as compared to those of chestnut cultivars grown in Switzerland (2.5–6.9 g kg^{-1}).[3] In spite of these differences, our results concur with other reports in which sucrose is the main free sugar in chestnuts with lower quantities of glucose, fructose, and maltose.[12,17–20]

CONCLUSIONS

Twenty-three attributes were used to describe sensory characteristics of cultivars representing chestnut species of diverse pedigrees (Table 1). While peelability, sweetness, and texture have been used to evaluate sensory characteristics of *C. sativa* chestnut cultivars in Europe, this study demonstrated that many other flavor terms can be used as descriptors by trained panelists to characterize several cultivars of varying pedigrees. Additionally, chestnuts grown in North America are characterized by a nutty flavor, but varied in six sensory attributes, including peelability, initial firmness, dissolvability, and mustard, sweet, and sour flavors (Table 2). While intensity ratings of sweetness differed among cultivars, quantification of the various free sugars by GLC provided more detailed information, including sucrose, glucose, fructose, and maltose contents of the chestnuts (Table 3). Colossal chestnuts grown in California were distinguishable from those grown in Michigan and Missouri (Fig. 1), which may be attributed to extreme climatic conditions (high temperatures and drought) in the 2 months preceding harvest. Thus various cultivars and sites of cultivation in North America contribute to the array of chestnut flavors in the marketplace.

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