Food Research International 131 (2020) 108999

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Comparison of two rapid descriptive sensory techniques for profiling and screening of drivers of liking of sorghum breads

Lorena Andrade de Aguiar[a], Daniele Bobrowski Rodrigues[a], Valéria Aparecida Vieira Queiroz[b], Lauro Melo[c], Lívia de Lacerda de Oliveira Pineli[a,*]

[a] Faculty of Health Sciences, University of Brasilia, Campus Darcy Ribeiro, Brasilia, DF 70910-900, Brazil
[b] Brazilian Agricultural Research Corporation (Embrapa) Milho e Sorgo, Sete Lagoas, MG 35701-970, Brazil
[c] Department of Biochemical Engineering, School of Chemistry, Federal University of Rio de Janeiro, Rio de Janeiro, RJ 21941-909, Brazil

ARTICLE INFO

Keywords:
Gluten-free bread
Check-all-that-apply
Optimized descriptive profile
Descriptive analysis
Sorghum genotypes
Drivers of liking

ABSTRACT

Rapid descriptive methods have emerged as a relatively simple alternative for screening the sensory attributes of products that drive their liking, and may contribute to identify sorghum genotypes with potential for development of gluten-free breads with higher consumer acceptance. Two rapid techniques, Check-All-That-Apply (CATA) and Optimized Descriptive Profile (ODP), were herein compared on their ability to describe, discriminate and identify the drivers of liking of sorghum breads. Gluten-free bread formulations were developed using flours from selected sorghum genotypes (CMSS005, BR 501, BRS 332, BRS 330, BRS 305 and 1167048), besides commercial sorghum and rice flours. A semi-trained panel ($n = 18$) evaluated the samples using the ODP method, whereas consumers ($n = 124$) completed the CATA questionnaire and rated the liking in a 9-point hedonic scale. A total of 24 and 11 sensory descriptors were perceived by assessors as different among samples for CATA and ODP, respectively, with color and appearance-related attributes critical to discriminate samples in CATA, whereas flavor and texture descriptors had also prominent contribution in ODP. A similar pattern of sample distribution was noticed for both methods, which were shown to be highly and positively correlated ($RV = 0.92$, $p < 0.002$). Genotypes influenced the consumer perception of sorghum breads, being the BRS 332 and the CMSS005 breads among the most and the least accepted samples for either consumer segment, respectively. While 10 drivers of liking were identified by CATA, including 'appearance of whole flour breads', 'uniform alveoli', 'neutral flavor' and 'soft aroma', in ODP 'crumb color', 'crust color', 'spots' and 'traditional bread aroma' drove bread acceptance. In summary, both methods were successfully applied and provided similar pattern of sample discrimination, whereas the attributes used for sample characterization, as well as those identified as drivers of liking were generally different. The ODP offers a simpler option for a quantitative perspective, while CATA remains as an easy method considering qualitative aspects, being clearly faster than ODP.

1. Introduction

Sorghum (*Sorghum bicolor* L. Moench) stands as the fifth most produced cereal worldwide (57.6 million tons) (FAOSTAT, 2017). The ability to grow under variable agroclimatic conditions, including those severe as drought and heat stresses and low fertile soils, outlines the strategic position of sorghum in terms of food security, not to mention its relatively low production cost (Hadebe, Modi, & Mabhaudhi, 2017; ICRISAT/FAO, 2004). Although established as staple food in semi-arid regions of Africa and Asia, sorghum is generally underutilized as human food source in many Western countries, with the largest production share supplying animal feed and bioethanol industries (Stefoska-Needham, Beck, Johnson, & Tapsell, 2015; Taylor, Schober, & Bean, 2006). Nonetheless, this starchy cereal has been gathering increasing attention on the grounds of its gluten-free status, in a scenario of high prevalence of gluten-related disorders and in particular, celiac disease, conditions for which the only accepted treatment is a strict gluten-free diet (Pontieri et al., 2013).

Sorghum exhibits a wide genetic diversity, expressed as a broad range of grain sizes, shapes and colors that can be found in nature. Pericarp colors range from white to brown, being associated to a variable content of phenolic compounds (Awika, Rooney, Wu, Prior, &

* Corresponding author.
E-mail addresses: loryandrade1@gmail.com (L.A.d. Aguiar), danielebobrowskirodrigues@gmail.com (D.B. Rodrigues), valeria.vieira@embrapa.br (V.A.V. Queiroz), lauro@eq.ufrj.br (L. Melo), liviadelacerda@gmail.com (L.d.L.d.O. Pineli).

https://doi.org/10.1016/j.foodres.2020.108999
Received 9 September 2019; Received in revised form 24 December 2019; Accepted 11 January 2020
Available online 18 January 2020
0963-9969/

Cisneros-Zevallos, 2003; Dykes, Rooney, Waniska, & Rooney, 2005). As the chemical composition of nutrients and phytochemicals of sorghum grains varies within the different accessions and genotypes, it may indicate grain traits appropriate for specific end-uses (Visarada & Aruna, 2019). Furthermore, this genetic diversity has been providing opportunities for improvement programs, and several hybrids more suitable for food have been developed (Tuinstra, 2008). Over the past decade, the Brazilian Agricultural Research Corporation (Embrapa) has developed research to identify high-yield sorghum genotypes with nutritional and technological potential to be used in products intended for human consumption (Martino et al., 2012; Queiroz et al., 2011). Efforts to develop improved grains are important, but must be coupled with an understanding of how consumers perceive food products prepared with those grains, even for guiding more adjusted agronomic strategies. In other words, evaluating the usage of selected sorghum genotypes in real foods, from the perspective of their sensory and technological quality, is critical to establish their actual potential for food technology purposes, with the preparation of gluten-free breads offering one of the major avenues for sorghum application (Pineli, Zandonadi, Botelho, de Oliveira, & Figueiredo, 2015; Schober, Messerschmidt, Bean, Park, & Arendt, 2005).

Sensory methods have a central role in product development processes and are of particular interest when evaluating food products prepared with ingredients that are not part of the eating habit of a population, as sorghum for several countries (Caporale, Policastro, Carlucci, & Monteleone, 2006). Understanding how the sorghum genotypes would impact the sensory profile of breads, and the sensory attributes of those sorghum breads that drive the consumer acceptability, i.e., their drivers of liking, might guide the development of sorghum-based gluten-free breads that meet consumer quality expectations. Of note, this strategy could lead to a more widespread inclusion of sorghum in the diet, effectively contributing for dietary diversity and food security. In practice, the association of descriptive and affective sensory methods has been employed for getting information on how perceptible differences in sensory attributes of samples affect consumer hedonic responses (Delgado & Guinard, 2011; Guinard, Uotani, & Schlich, 2001).

It is known that classical descriptive methods, particularly the Quantitative Descriptive Analysis (QDA), constitute an effective tool to achieve a detailed sensory description of a food product (Stone, Bleibaum, & Thomas, 2012). Widely accepted as the "gold standard" for sensory profiling, the QDA method is based upon the ability of a highly trained panel, whose discriminative abilities are statistically validated, to provide a qualitative and quantitative description of sample attributes (Stone et al., 2012). However, the use of traditional techniques is a costly, laborious, and mainly lengthy process due to the long time required for panel training, and other rapid methods have been gaining relevance as an alternative to get faster and less expensive responses, without compromising the reliability of the data (Aguiar, Melo, & de Oliveira, 2018; Ares & Varela, 2014). In general, the massive requirements of time and resources have hampered not only the rapid sensory profile assessment but also the systematic screening of a high number of samples (Labbe, Ritz, & Hugi, 2004). The basic principles underlying the application of the most diffused emerging techniques, as well as aspects of their validation against the classical descriptive methods, have been reviewed elsewhere (Aguiar et al., 2018; Varela & Ares, 2012).

Among the rapid methods, CATA (Check-All-That-Apply) likely represents the most mature technique in terms of application at both academic and industrial levels (Ares & Varela, 2018). By analyzing the frequencies with which the sensory terms listed in a questionnaire are used by consumers to describe a sample, CATA provides information about the consumers' perception of the product, which can be related to its acceptance (Adams, Williams, Lancaster, & Foley, 2007; Dooley, Lee, & Meullenet, 2010). However, this method does not allow for quantitative measures, as they are based on frequencies and not rating. Besides, low discrimination power of CATA method has been reported for sets of similar samples (Ares et al., 2015; Mello, Almeida, & Melo, 2019).

More recently, a rapid method termed Optimized Descriptive Profile (ODP) was developed to address also the magnitude of sensory attributes, based on an optimized evaluation protocol that requires only a brief training of the assessors (Silva et al., 2012). In contrast to the extensive training process using reference samples traditionally performed in QDA prior to the final evaluation, in ODP reference materials are present for consultation during the data collection. This eliminates the need for sensory memory formation and helps the allocation of perceived intensities on the scale, so semi-trained panels attain consistent evaluations. Markedly, ODP has been showed to provide similar results to those achieved with QDA, with evident time reduction (Aguiar et al., 2018; Silva et al., 2013). However, this method has received relatively limited attention specially when compared to CATA, and has not been applied, for instance, for sensory characterization of bakery products. Furthermore, except for Ranking Descriptive Analysis (Silva et al., 2013), no direct comparison between the data achieved by ODP and other rapid descriptive methods is available in the literature. In this context, we compared the ability of two rapid descriptive techniques, CATA and ODP, to discriminate gluten-free breads made with flours from different sorghum genotypes in relation to their sensory profile, as well as to identify the sensory attributes of sorghum breads that drive consumer liking.

2. Material and methods

2.1. Samples and ingredients

Sorghum grains were grown in the experimental field of Embrapa *Milho e Sorgo* (Sete Lagoas-MG, Brazil) in December of 2015 and transported to the University of Brasília (UnB, Brasília-DF, Brazil), where they were manually selected by removal of glumes and stored at 4 °C until grinding. Composite samples (8 kg) of whole grains of each sorghum genotype, namely CMSS005 and BR 501 (white pericarp, tannin-free), BRS 330 and BRS 332 (bronze pericarp, tannin-free), and 1167048 and BRS 305 (brown pericarp containing tannins) were ground in a high speed grain mill (Bosch Nutrimill Classic 760200, St. George-UT, USA) to obtain six whole sorghum flours. Flours were vacuum-packed in polyethylene bags and stored under refrigeration (4 °C) until bread preparation. Commercial white sorghum whole flour (Bob's Red Mill, Milwaukie-OR, USA) and rice flour (Tio João, Pelotas-RS, Brazil) used for comparison purposes to prepare "traditional" gluten-free breads (as these flours traditionally replace the wheat flour in gluten-free products) were purchased from a local market (Brasília-DF, Brazil), as well as all the ingredients used for baking. Materials used to prepare the reference samples used in ODP and their respective suppliers are specified in Table S1.

2.2. Gluten-free bread formulations and bread-making process

Loaves were prepared with either flours from each one of the six genotypes of sorghum, commercial sorghum or rice, totalizing eight different gluten-free breads. The proportion of all ingredients used in baking was the same regardless the sample, and the base formulation, expressed in flour basis (g/100 g flour mix), is showed in Table 1. For the bread preparation, dry ingredients were mixed together in a food processor (model RI7782-01, Philips Walita, China), followed by addition of water and oil. Dough was kneaded until a homogeneous mass was reached. After that, whole eggs and egg whites were added and the mixture further homogenized. Finally, the pre-activated yeast (sugar solution, 37–43 °C for 10 min) was incorporated and dough pieces transferred to greased aluminum loaf pans, where they were proofed for 25 min (37 °C, 70% relative humidity). Proofed doughs were baked in preheated oven (Brastemp, Brazil) for 45 min at 190 °C. Loaves (approx.

Table 1
Base formulation for preparation of the gluten-free breads.

Ingredients	Proportion (%)[a]
Sorghum or rice flours	61
Potato starch	28
Sweet manioc starch	11
Xanthan gum	1
Brown sugar	8
Salt (NaCl)	2
Sunflower oil	15
Water	86
Whole eggs	17
Egg whites	10
Instant dry yeast (*Saccharomyces cerevisiae*)	3
Brown sugar[b]	3
Water[b]	31

[a] The proportion of all ingredients is expressed in flour basis (g/100 g flour mix).
[b] Further brown sugar and water were employed for yeast proofing. Formulations were developed from bread recipes from conventional cookbooks, which were systematically tested and modified by using those ingredients that showed better properties in breads prepared with sorghum flours, as reviewed by Pineli et al. (2015).

500 g) were removed from the pans, cooled down to room temperature and stored unsliced in capped polyethylene containers. All bread samples were evaluated within the same day, served as 1 cm-thick slices of bread.

2.3. Sensory evaluation

Affective and descriptive sensory tests were performed in two different settings, at the Laboratory of Sensory Evaluation of the UnB and at a health food store (Shizen), both located in Brasília-DF (Brazil). Regular consumption of breads and willingness to collaborate were the prerequisites for participation. Protocols used in this study were approved by the Research Ethics Committee of the UnB (n° 1.331.651). Prior to the sensory evaluation, the objectives of the research were properly communicated and an informed consent form was signed by all the subjects. Demographic information was collected in the recruitment questionnaire.

For either method, samples of each treatment were prepared in batches of three loaves each per evaluation. More specifically, three aluminum loaf pans of each treatment were baked at the same time, in the same oven under the same conditions, and this process was repeated for each section held. The two extremities of each loaf, as well as broken slices were eliminated after slicing. Slices from these different loaves were randomly served to consumers. For CATA analyses, two sessions were held, totalizing 48 loaves. For ODP tests, 45 sections were held (15 sessions per attribute, in triplicate) and a total of 135 loaves of each treatment and 1080 loaves considering all the treatments were prepared.

2.3.1. Check-All-That-Apply (CATA)

Initially, the sensory descriptors used for the CATA analysis were raised applying the Kelly's Repertory Grid Method (Moskowitz, 1983) with participation of 10 untrained assessors, totalizing a set of three grid procedures of sample comparison. The most relevant sensory attributes (regarding appearance, aroma, flavor and texture) that characterize the breads were then selected by consensus among the assessors under the supervision of a panel moderator. Total session duration was 40 min.

Once the final list of sensory descriptors was defined, breads were subjected to CATA analysis with a participation of 124 consumers (Adams, Williams, Lancaster, & Foley, 2007). Samples were monadically served in disposable plates coded with three-digit random numbers, following a balanced presentation order (XLSTAT software). Consumers received the CATA questionnaire, that consisted of a list containing the 48 sensory terms raised by the grid method, divided by category (15 for appearance, 6 for aroma, 7 for color, 8 for flavor and 12 for texture), from which they should check all the attributes they considered that applied to describe each bread. The order of attributes of each category was balanced among consumers.

2.3.2. Optimized descriptive profile (ODP)

Structured questionnaires were applied to candidates to evaluate their familiarization with sensory terms, ability to work with unstructured scales, time availability and whether they presented any health condition or impediment for consuming the product that would preclude their participation. Based on their answers, 22 individuals were recruited to participate of a pre-selection for the sensory evaluation. This step consisted of a series of four triangular tests to assess their discriminatory capacity, and the selection criterion was the sensory acuity in at least 75% of these tests, as recommended by Meilgaard, Civille, and Carr (2006). Samples used in triangular tests corresponded to gluten-free loaves containing 2% and 5% salt, previously subjected to a discriminative test to confirm that there was a significant difference between them ($p < 0.05$). Twenty assessors were pre-selected and 18 completed the sensory evaluation. According to Silva, Minim, Silva, Peternelli, and Minim (2014), the minimum number of assessors necessary to perform ODP is 16 people.

Pre-selected assessors consensually defined the descriptive terminology employed during the ODP analysis, as well as the reference materials corresponding to the extremes of intensity (weak and strong) of each attribute evaluated. This was done through the 'previous list' technique (Minim & Silva, 2016), using the sensory terms previously elicited for the CATA analysis to describe the breads. Definitions for the 15 attributes evaluated in ODP test and references used for their maximum and minimal intensities are outlined in Table S1. Moreover, a familiarization session was carried out to clarify the definition of the attributes, aiming to standardize the evaluation procedure and avoid interpretation errors.

The final evaluation of breads was conducted through comparison of the samples with the references using an intensity scale, which was anchored at the extremities by the terms 'weak' and 'strong' represented by the reference materials. For that purpose, each assessor received, simultaneously, all the eight samples and the reference materials for a specific attribute under evaluation (see Fig. S1). The panel was requested to rate the perceived intensities of each attribute in a 9 cm unstructured scale, and the sensory scores were then measured with a ruler (Silva et al., 2013). Samples were evaluated according to the attribute-to-attribute method, which means that only one attribute was evaluated per session, so a total of 45 sessions were held (15 attributes evaluated in triplicate) within a period of three months (Ishii, Chang, & O'Mahony, 2007; Silva et al., 2012).

2.3.3. Consumer acceptance testing

Bread samples were submitted to the acceptance test using a 9-point structured hedonic scale ranging from "disliked extremely" (1) to "liked extremely" (9) for appearance, flavor, aroma, texture and overall liking. Acceptance testing and CATA question were performed in the same session (consumers, $n = 124$).

2.4. Statistical analyses

Statistical analyses were conducted by the XLSTAT 2015 software (Addinsoft, Paris, France). Non-parametric Cochran's Q test was applied to CATA counts to assess whether there was significant difference in consumer perception for a given attribute among the different samples, and was followed by pairwise comparison tests using the Bonferroni procedure (McNemar), both at 5% significance (Worch & Piqueras-Fiszman, 2015). Correspondence analysis (CA) based on chi-squared distances was performed to achieve a sensory map of samples (Meyners, Castura, & Carr, 2013), and the test of independence between rows and columns was carried out at 5% of significance.

Sensory scores for each attribute evaluated in ODP were analyzed by two-way ANOVA with sample and assessor (and their interaction) as the variation sources, followed by Fisher's LSD test ($\alpha = 5\%$). ODP data were also analyzed by Principal Component Analysis (PCA) (Silva et al., 2012).

The Regression Vector coefficient (RV) was calculated between the sample configurations obtained in CATA (CA) and ODP (PCA) to analyze similarities between sample distributions for both methodologies (Robert & Escoufier, 1976).

Sensory scores obtained in acceptance testing were compared by two-way ANOVA, with samples and consumers as the variation sources, followed by Fisher's LSD test ($\alpha = 5\%$). Hierarchical cluster analysis (agglomerative clustering using Euclidean distance for Ward method) was applied on the acceptance data (overall liking) so clusters of consumers exhibiting different liking patterns were identified. Then, mean liking scores were compared between the clusters by Student's *t* test ($p < 0.05$). Moreover, the impact of sensory attributes identified in both CATA and ODP analyses on consumer's acceptance was assessed employing, respectively, PLS regression (Tenenhaus, Pages, Ambroisini, & Guinot, 2005) and penalty analyses (Meyners et al., 2013).

3. Results and discussion

3.1. CATA sensory profile

The Repertory Grid method resulted in 48 attributes to be applied in the CATA question: 15 for appearance, 6 for aroma, 7 for color, 8 for flavor and 12 for texture. However, only 24 descriptors were perceived as different among the samples by consumers ($p < 0.05$, Table 2). This is indicative of the poor discrimination power of CATA for samples or attributes that show little differences among them, as observed by Mello et al. (2019) and Ares et al. (2015).

Regardless the sample, the most frequently used terms to describe the gluten-free breads evaluated in this study comprised the 'soft aroma', 'soft crumb' and 'neutral flavor', which were equally mentioned for all treatments ($p > 0.05$). The neutral flavor in sorghum preparations was reported by Ciacci et al. (2007) and may represent an additional advantage when considering this cereal for preparation of gluten-free products. Among the lowest absolute frequencies of use for either sample were the attributes 'burnt odor', 'smoke odor', 'acid taste' and 'coffee flavor', with no statistical differences noticed among samples as well ($p > 0.05$). Regarding appearance, samples prepared with selected sorghum genotypes did not differ in the frequency of use of the terms 'irregular alveoli' and 'uniform alveoli' ($p > 0.05$). The same sensory response is expected for these descriptors given their complementarity. The brown 1167048 sample differed from the brown BRS 305 and white CMSS005 by presenting lower frequency of use of 'large alveoli'. This sample was also the only sorghum bread that did not differ from the commercial sorghum bread regarding all the aforementioned attributes related to bread alveoli. Commercial sorghum was generally described as having smaller, less irregular and, in line, more uniform alveoli than selected sorghum breads.

Overall, the frequency of using 'appearance of white flour breads' for describing the traditional breads exceeded that of selected white sorghum breads, which exceeded that of bronze and brown sorghum breads ($p < 0.05$). The commercial white sorghum bread did not differ ($p > 0.05$) from the white CMSS005 though, the selected sorghum genotype that resulted in the whole-product that closest resembled the appearance of white or even refined flour breads. Moreover, the white BR 501 bread was as checked as the bronze BRS 332 one ($p > 0.05$). As expected, bronze and brown breads were described as having 'appearance of whole flour breads' in a greater extent when compared to white sorghum and rice breads.

'Black dots in crumb', 'brown dots in crumb' and 'black dots in crust' were not checked for the rice bread, which is not surprisingly considering this type of flour. This sample only differed from the commercial sorghum bread concerning its lower frequency in the use of 'black dots in crumb' in contrast to the latter ($p < 0.05$). In its turn, commercial sorghum bread was significantly less checked for 'brown dots in crumb' when compared with breads prepared with selected sorghum genotypes, except for the white CMSS005 sample, and did not differ from them in relation to the frequency of mentioning black dots in either bread crumb or crust. Within the selected sorghum genotypes, in general samples were similarly perceived as having brown or black dots in their crumbs or crusts. Particular differences were found for white CMSS005 sorghum bread, less checked for the presence of brown dots in crumb than the brown 1167048 one, while the white BR 501 bread was more checked for 'black dots in crumb' than both brown breads. For this attribute, the other white bread (CMSS005) and even the bronze BRS 332 were more checked than the brown BRS 305 sample. The greater consumer's perception that white sorghum breads present more black dots than the brown breads is likely related to the darker color of the latter (see Fig. 1), which precludes the possibility of observing as many black dots in the crumb as it is possible to see in white breads, where the spots become more apparent by contrast.

Table 2 indicates that the sorghum genotypes indeed influenced the perception of color descriptors, with all the attributes of this category included in the CATA question perceived by consumers as different among the samples ($p < 0.05$). 'Light color' and 'cream color' attributes were significantly less or even not checked to describe bronze and brown breads, that were described as presenting more 'chocolate' and 'dark brown' colors than white sorghum breads. In the same way, white sorghum breads received null or very limited mention for the color attributes 'chocolate' and 'dark brown' and largely surpassed the frequencies of use the terms 'light color' and 'cream color' of both bronze and brown sorghum breads. For all these attributes, samples prepared with the two white sorghum genotypes did not differ from each other, as well as those four bread preparations from bronze and brown genotypes, with a remarkable exception to the bronze BRS 332 bread checked in a lesser extent for 'chocolate' and 'dark brown color' than others. Interestingly, the bronze BRS 332 was statistically more characterized as presenting a 'caramel color' than all the other white, bronze and brown sorghum breads, attribute that also differentiated the brown BRS 305 from the white BR 501 sample. The attribute 'dark crust' was important to differentiate brown breads against the white ones. White sorghum samples did not differ from commercial white sorghum bread in relation to the 'French bread color', but they were less checked for this attribute than the rice bread.

Concerning to aroma attributes, white CMSS005 bread was more checked for the 'raw bread aroma' than the bronze BRS332 one, whereas both were similarly perceived by consumers in comparison to the other traditional and sorghum samples. The discriminative flavor descriptors 'bitter' and 'bitter aftertaste' were more perceived for commercial sorghum bread than rice and other white sorghum breads. This bread was also more bitter than bronze BRS 330 and brown 1167048 breads. Within the selected sorghum breads, except for the 1167048 sample that was significantly more regarded as having bitter aftertaste than the BR 501, no differences were found in the frequency with which this term was used. Furthermore, significant differences ($p < 0.05$) were found for five texture related attributes. The term 'rubbery' was more checked for rice bread than for the majority of sorghum breads, namely commercial white, white BR 501, bronze BRS 332 and brown 1167048 breads, whereas no difference was found within the sorghum samples. The remaining four texture attributes 'hard crust, 'sticking in the roof of your mouth', 'moist crumb' and 'similar to conventional breads' were indicated by the Cochran's Q test as different ($p < 0.05$) but the *posteriori* McNemar test was not able to detect these differences, in such a way that all treatments are shown in Table 2 with the same superscript letter for these attributes. Therefore, the most relevant sensory attributes identified by untrained assessors to

Table 2
Absolute frequencies of sensory attributes checked for the different gluten-free breads, CATA (n = 124).

Attributes		Rice	Commercial	CMSS005	BR 501	BRS 330	BRS 332	1167048	BR 305	*p*-value (Cochran's Q)
Appearance	SH (slice height)	11	13	10	7	7	10	16	8	0.1916
	LA (large alveoli)	18 ^{ab}	7 ^{a}	47^{c}	34 ^{bc}	29 ^{bc}	30 ^{bc}	20 ^{ab}	50^{c}	< 0.0001
	IA (irregular alveoli)	39^{b}	18 ^{a}	46^{b}	43^{b}	42^{b}	36 ^{ab}	28 ^{ab}	46^{b}	< 0.0001
	UA (uniform alveoli)	37 ^{ab}	54^{b}	25 ^{a}	27 ^{a}	26 ^{a}	28 ^{a}	39 ^{ab}	23 ^{a}	< 0.0001
	AWhiteB (appearance of white flour breads)	59 ^{e}	43 ^{de}	23 ^{cd}	14 ^{bc}	0 ^{a}	1 ^{ab}	0 ^{a}	0 ^{a}	< 0.0001
	AWholeB (appearance of whole flour breads)	13 ^{a}	27 ^{abc}	24 ^{ab}	35 ^{bc}	64 ^{d}	75 ^{d}	70 ^{d}	50 ^{cd}	< 0.0001
	TC (thin crust)	55	54	43	46	35	48	47	43	0.0515
	SC (soft crust)	36	36	35	31	37	38	32	38	0.9325
	HC (hard crust)	34	30	31	34	33	28	27	38	0.7227
	SmC (smooth crust)	37	30	27	35	21	24	32	22	0.0370
	BrownDCrumb (brown dots in crumb)	0 ^{a}	9 ^{ab}	15 ^{bc}	29 ^{cd}	30 ^{cd}	32 ^{cd}	37 ^{d}	25 ^{cd}	< 0.0001
	BDCrust (black dots in crust)	0 ^{a}	9 ^{ab}	7 ^{ab}	13^{b}	11 ^{ab}	17^{b}	21^{b}	7 ^{ab}	< 0.0001
	BDCrumb (black dots in crumb)	0 ^{a}	20 ^{bcd}	30 ^{cd}	35 ^{d}	16 ^{bcd}	28 ^{cd}	13 ^{bc}	5 ^{ab}	< 0.0001
	RoundLT (rounded loaf top)	18	12	12	11	8	12	10	14	0.4198
	RegLT (regular loaf top)	17	14	16	14	14	12	18	12	0.8476
Aroma	Acid	6	10	5	6	8	3	7	12	0.1311
	RBA (raw bread aroma)	30 ^{ab}	20 ^{ab}	37^{b}	31 ^{ab}	23 ^{ab}	13 ^{a}	21 ^{ab}	25 ^{ab}	0.0017
	SmkO (smoke odor)	3	2	5	3	4	2	8	8	0.1565
	BO (burnt odor)	2	1	0	1	5	2	6	4	0.0582
	YA (yeast aroma)	27	27	23	23	18	29	21	22	0.5025
	SA (soft aroma)	74	74	66	73	75	82	62	68	0.1282
Color	DBC (dark brown color)	0 ^{a}	0 ^{a}	0 ^{a}	2 ^{a}	34 ^{bc}	22^{b}	46^{c}	53^{c}	< 0.0001
	LC (light color)	79^{c}	57 ^{bc}	56 ^{bc}	42^{b}	1 ^{a}	11 ^{a}	0 ^{a}	0 ^{a}	< 0.0001
	CreamC (cream color)	39^{b}	54 ^{bc}	68^{c}	55 ^{bc}	2 ^{a}	12 ^{a}	2 ^{a}	1 ^{a}	< 0.0001
	CaramelC (caramel color)	6 ^{a}	16 ^{ab}	16 ^{ab}	30^{b}	17 ^{ab}	54^{c}	13 ^{ab}	4 ^{a}	< 0.0001
	ChocolateC (chocolate color)	0 ^{a}	2 ^{a}	1 ^{a}	0 ^{a}	75^{c}	25^{b}	65^{c}	80^{c}	< 0.0001
	FBC (French bread color)	30^{c}	15 ^{bc}	9 ^{ab}	8 ^{ab}	0 ^{a}	0 ^{a}	0 ^{a}	0 ^{a}	< 0.0001
	DCrust (dark crust)	3 ^{a}	7 ^{abc}	3 ^{ab}	3 ^{a}	17 ^{abcd}	18 ^{bcd}	19 ^{cd}	25 ^{d}	< 0.0001
Flavor	Sweet	42	25	35	45	39	38	37	36	0.0983
	AS (astringent)	3	10	12	3	7	9	7	10	0.0782
	Bitter	2 ^{a}	23^{b}	2 ^{a}	5 ^{a}	5 ^{a}	8 ^{ab}	2 ^{a}	11 ^{ab}	0.0000
	AcidT (acid taste)	3	5	5	4	7	5	5	1	0.5288
	Neutral	62	46	56	54	53	45	48	48	0.2104
	BAT (bitter aftertaste)	9 ^{a}	36^{c}	10 ^{ab}	5 ^{a}	17 ^{abc}	20 ^{abc}	28 ^{bc}	17 ^{abc}	< 0.0001
	CF (coffee flavor)	1	0	1	3	3	3	5	5	0.2199
	YF (yeast flavor)	24	18	22	18	13	20	18	16	0.4803
Texture	Rubbery	30^{b}	7 ^{a}	11 ^{ab}	11 ^{a}	13 ^{ab}	10 ^{a}	8 ^{a}	19 ^{ab}	< 0.0001
	Cohesive	24	18	22	12	17	17	12	14	0.1385
	Compact	15	16	13	13	11	11	8	14	0.7092
	CCrust (crunchy crust)	14	18	16	15	20	16	23	21	0.5559
	HCrust (hard crust)	4 ^{a}	2 ^{a}	5 ^{a}	12 ^{a}	11 ^{a}	8 ^{a}	8 ^{a}	11 ^{a}	0.0420
	TCrust (thick crust)	3	4	5	5	10	6	8	5	0.4441
	Grainy	24	31	30	36	28	24	38	23	0.0727
	SRYM (sticking in the roof of your mouth)	3 ^{a}	1 ^{a}	5 ^{a}	2 ^{a}	6 ^{a}	11 ^{a}	2 ^{a}	8 ^{a}	0.0068
	SCrumb (soft crumb)	53	58	53	59	66	63	65	57	0.3867
	MC (mushy crumb)	23	33	24	32	25	35	22	25	0.1434
	MoistC (moist crumb)	36 ^{a}	25 ^{a}	38 ^{a}	30 ^{a}	27 ^{a}	40 ^{a}	35 ^{a}	43 ^{a}	0.0420
	SCB (similar to conventional breads)	22 ^{a}	22 ^{a}	11 ^{a}	9 ^{a}	13 ^{a}	13 ^{a}	12 ^{a}	7 ^{a}	0.0062

Frequencies with which sensory terms were checked in the CATA question. Different letters in the same row indicate significant difference ($p < 0.05$). SH: slice height, LA: large alveoli, IA: irregular alveoli, UA: uniform alveoli, AWhiteB: appearance of white flour breads, AWholeB: appearance of whole flour breads, TC: thin crust, SC: soft crust, HC: hard crust, SmC: smooth crust, BrownDCrumb: brown dots in crumb, BDCrust: black dots in crust, BDCrumb: black dots in crumb, RoundLT: rounded loaf top, RegLT: regular loaf top, RBA: raw bread aroma, SmkO: smoke odor, BO: burnt odor, YA: yeast aroma, SA: soft aroma, DBC: dark brown color, LC: light color, CreamC: cream color, CaramelC: caramel color; ChocolateC: chocolate color, FBC: French bread color, DCrust: dark crust; AS: astringent; AcidT: acid taste; BAT: bitter aftertaste, CF: coffee flavor, YF: yeast flavor, CCrust: crunchy crust, HCrust: hard crust, TCrust: thick crust, SRYM: sticking in the roof of your mouth, SCrumb: soft crumb, MC: mushy crumb, MoistC: moist crumb, SCB: similar to conventional breads. Rice: rice bread; Commercial: commercial white sorghum bread; 1167048: brown 1167048 sorghum bread; BR 305: brown BR 305 sorghum bread; BRS 330: bronze BRS 330 sorghum bread; BRS 332: bronze BRS 332 sorghum bread; CMSS005: white CMSS005 sorghum bread; BR 501: white BR 501 sorghum bread.

differentiate the breads and, in particular, selected sorghum genotypes in CATA, were those concerning the color and appearance, besides the 'raw bread aroma'.

Correspondence Analysis (CA) was applied to the CATA data to generate the sensory map shown in Fig. 2. The first and second dimensions of the map explained 64.4% and 15.1% of the experimental data variance, respectively, representing 79.4% of total variance ($p < 0.0001$).

In the first dimension (F1 axis) samples were classified into two main groups, one located at the left side (negative in F1 axis) composed by brown (BRS 305 and 1167048) and bronze (BRS 332 and BRS 330) sorghum breads, with commercial rice and white sorghum, and the white (CMSS005 and BR 501) sorghum breads composing the second group at the right side of the map (positive in F1 axis). The first dimension was polarized mainly by color and appearance attributes, being the negative extremity represented by terms 'chocolate color', 'dark brown color', 'dark crust' and 'brown dots in crumb', and the opposite extremity represented by 'light', 'cream' and 'French bread' colors besides 'appearance of white flour breads'. This is in agreement with the fact that these terms were extensively used by consumers to

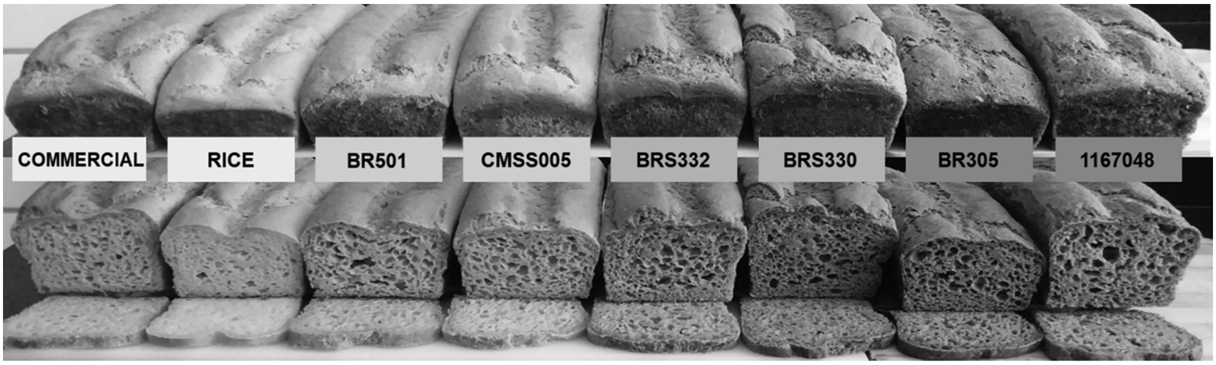

Fig. 1. Gluten-free breads developed and evaluated in this study. From the left to the right: commercial white sorghum (commercial) and rice bread (rice), followed by breads prepared with selected sorghum genotypes: white BR 501 and CMSS005, bronze BRS 332 and BRS 330, and brown BR 305 and 1167048.

describe and differentiate the breads as aforementioned, thereby explaining their association with the dimension with the largest explained variance.

In the F2 axis, sample localization approached the origin to a certain extent, with texture, color and appearance related terms slightly more polarized throughout this axis. Although corresponding to the lowest explained variance, this dimension was key to explain the separation of bronze BRS 332 bread on the negative side of F2 axis from its bronze counterpart and brown samples. In fact, the bronze BRS 332 bread was significantly more characterized by consumers as having 'caramel color', term located at the negative extremity of F2 axis. In addition, the opposite side of this dimension was represented by the terms 'dark

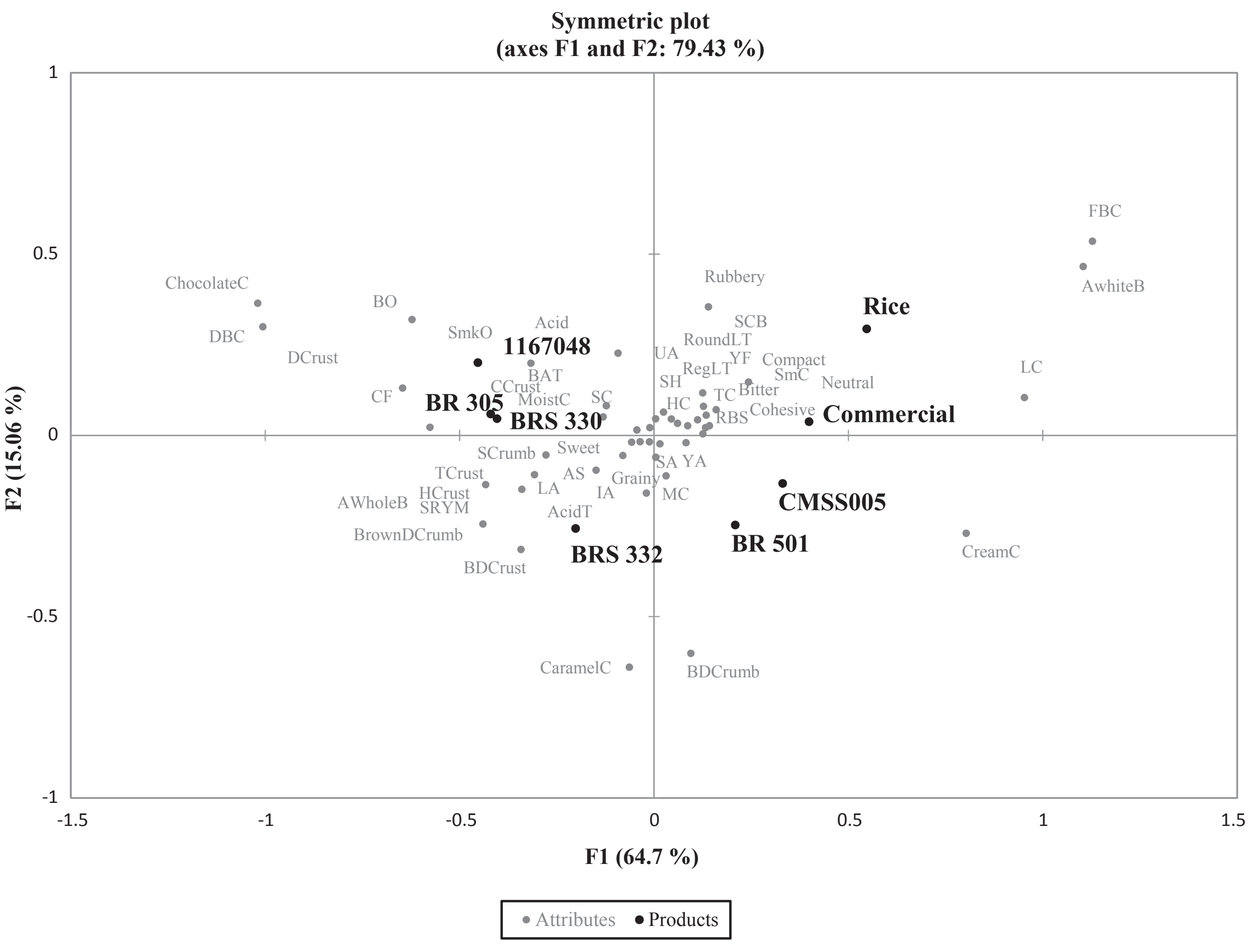

Fig. 2. Sensory descriptive map resulting from Correspondence Analysis performed on the CATA data (n = 124). Rice: rice bread; Commercial: commercial white sorghum bread; 1167048: brown 1167048 sorghum bread; BR 305: brown BR 305 sorghum bread; BRS 330: bronze BRS 330 sorghum bread; BRS 332: bronze BRS 332 sorghum bread; CMSS005: white CMSS005 sorghum bread; BR 501: white BR 501 sorghum bread. SH: slice height, LA: large alveoli, IA: irregular alveoli, UA: uniform alveoli, AWhiteB: appearance of white flour breads, AWholeB: appearance of whole flour breads, TC: thin crust, SC: soft crust, HC: hard crust, SmC: smooth crust, BrownDCrumb: brown dots in crumb, BDCrust: black dots in crust, BDCrumb: black dots in crumb, RoundLT: rounded loaf top, RegLT: regular loaf top, RBA: raw bread aroma, SmkO: smoke odor, BO: burnt odor, YA: yeast aroma, SA: soft aroma, DBC: dark brown color, LC: light color, CreamC: cream color, CaramelC: caramel color; ChocolateC: chocolate color, FBC: French bread color, DCrust: dark crust; AS: astringent; AcidT: acid taste; BAT: bitter aftertaste, CF: coffee flavor, YF: yeast flavor, CCrust: crunchy crust, HCrust: hard crust, TCrust: thick crust, SRYM: sticking in the roof of your mouth, SCrumb: soft crumb, MC: mushy crumb, MoistC: moist crumb, SCB: similar to conventional breads.

Table 3
Mean scores of sensory attributes for each gluten-free bread obtained in ODP analysis using an unstructured 9-cm scale (n = 18).

Attributes	Bread samples								p-value (ANOVA)
	Rice	Commercial	CMSS005	BR 501	BRS 330	BRS 332	1167048	BR 305	
Color									
Crumb color	1.1^{e}	2.1^{d}	2.4^{d}	2.9^{d}	6.4^{b}	4.8^{c}	7.5^{a}	7.5^{a}	< 0.0001
Crust color	1.7^{g}	3.1^{f}	3.7^{e}	3.9^{e}	6.1^{c}	5.0^{d}	6.8^{b}	7.3^{a}	< 0.0001
Appearance									
Porosity	3.7^{d}	3.6^{d}	5.9^{ab}	6.3^{a}	5.6^{bc}	6.1^{ab}	6.0^{ab}	5.0^{c}	< 0.0001
Spots	0.3^{f}	2.2^{e}	3.1^{d}	4.5^{c}	5.6^{ab}	5.1^{bc}	6.2^{a}	4.6^{c}	< 0.0001
Crust softness	5.1^{a}	5.1^{a}	5.4^{a}	4.0^{b}	2.6^{c}	4.0^{b}	4.7^{ab}	4.0^{b}	< 0.0001
Aroma									
Yeast aroma	4.0^{a}	3.7^{a}	3.7^{ab}	3.7^{ab}	2.9^{bc}	3.5^{ab}	3.5^{abc}	2.6^{c}	0.041
Traditional bread aroma	3.1^{c}	3.4^{b}	3.7^{bc}	4.2^{ab}	4.6^{a}	4.9^{a}	4.0^{ab}	4.9^{a}	0.000
Toasted bread aroma	1.5^{c}	1.8^{bc}	1.9^{bc}	1.9^{bc}	2.8^{a}	2.4^{ab}	2.3^{ab}	3.0^{a}	0.001
Flavor									
Sweet taste	1.5	1.7	1.8	1.7	1.7	2.0	1.6	1.6	0.820
Yeast flavor	3.4	4.4	3.5	3.8	3.5	3.4	3.4	3.2	0.195
Bitter taste	1.1^{b}	2.3^{a}	1.2^{b}	1.2^{b}	1.6^{b}	1.4^{b}	1.7^{ab}	1.4^{b}	0.007
Astringent	1.1^{c}	2.0^{ab}	1.8^{ab}	2.2^{ab}	2.1^{ab}	1.6^{bc}	2.3^{a}	2.1^{ab}	0.016
Texture									
Adhesiveness	3.1^{c}	4.3^{ab}	3.8^{bc}	3.8^{bc}	5.0^{a}	5.2^{a}	4.9^{a}	4.8^{a}	< 0.0001
Hardness	1.7	1.5	1.8	2.0	2.2	1.6	2.2	2.1	0.164
Moisture	6.0	6.1	5.5	5.6	5.6	6.1	5.3	5.9	0.421

Different letters in the same row indicate significant difference (Fisher test, $p < 0.05$). Rice: rice bread; Commercial: commercial white sorghum bread; 1167048: brown 1167048 sorghum bread; BR 305: brown BR 305 sorghum bread; BRS 330: bronze BRS 330 sorghum bread; BRS 332: bronze BRS 332 sorghum bread; CMSS005: white CMSS005 sorghum bread; BR 501: white BR 501 sorghum bread.

brown color' and 'chocolate color', emphasized above as discriminative for the bronze BRS 332 bread from, respectively, brown samples and from its bronze counterpart plus brown samples (Table 2). For such attributes, bronze BRS 330 bread was statistically similar to brown ones, explaining in part their proximity in the map. Moreover, the F2 axis also showed the separation between traditional samples and selected white sorghum breads, associated in part to attributes 'appearance of white flour breads', 'brown dots in crumb' and 'rubbery'. In summary, through sensory mapping it was possible to observe the separation, in each one of the four quadrants, of the respective samples: traditional breads, white sorghum breads, bronze BRS 332 sorghum bread, and a group composed by bronze BRS 330 and brown sorghum breads.

3.2. ODP sensory profile

Semi-trained assessors perceived differences in the intensity of 11 out of the 15 attributes used to describe the breads evaluated in ODP analysis ($p < 0.05$, Table 3), indicating variable sensory profiles as showed in CATA by untrained assessors. Attributes that did not differ among the samples comprised 'sweet taste', 'yeast flavor', 'hardness' and 'moisture', the latter quantified with relatively high scores (above 5.3 on a 9 cm scale) for all samples, while the three formers together had maximum rating of 4.4.

Color attributes varied in a great extent among the samples. Mean scores for 'crumb color' ranged from 1.1 to 7.5 and increased as follows: rice < commercial and selected white sorghum < bronze BRS332 < bronze BRS330 < brown sorghum breads ($p < 0.05$). As in CATA, the color of bronze BRS 322 was perceived as less intense than the other bronze and brown breads, whereas the commercial white was statistically similar to selected white sorghum breads. 'Crust color' intensity increased in the same order showed for 'crumb color', but was slightly more discriminative. Brown BRS 305 bread color was scored as more intense than brown 1167048 sample, and commercial white sorghum bread was perceived as lighter than both white sorghum breads.

Significant differences ($p < 0.0001$) were also noticed among the samples for appearance attributes. Rice and commercial sorghum were similarly characterized regarding the bread alveoli, considered in the descriptor 'porosity', and presented lower mean intensities than selected sorghum breads. Among the sorghum breads, white BR 501 exhibited the highest mean score (6.3) for 'porosity', not differing from its white counterpart, bronze BRS 332 and brown 1167048, but scoring higher than bronze BRS 330 and brown BRS 305. Sorghum genotypes influenced the perception of spots (black or brown dots in crust or crumb) in the appearance of bread samples. Bronze and brown sorghum breads presented higher scores, as the pericarp pigmentation of these genotypes remains in whole flour, but brown BRS 305 and bronze BRS 332 breads did not differ from white BR 501. White CMSS005 sample presented lower spot intensity than other sorghum breads. The bread made with rice flour presented the lowest intensity mean (0.3), as expected, since the rice flour does not have any pigmentation. The attribute 'crust softness' was more intense in traditional, white CMSS005 and brown 1167048 breads, with intermediate mean scores that range from 4.7 to 5.4, whereas the lowest intensity (2.6) was found for the bronze BRS 330 one.

In the aroma category, all samples scored up to 4.0 for the descriptor 'yeast aroma, which was described as more intense in traditional breads than in bronze BRS 330 and brown BRS 305 samples. These two samples, on the other hand, scored higher for 'toasted bread aroma' in contrast to traditional and white sorghum breads, not differing from their color counterparts. Nonetheless, this attribute was also perceived as weak by semi-trained assessors for all breads (values up to 3.0). The last descriptor of this category, 'bread aroma' was found to be more intense in selected sorghum breads (mean scores ranging from 4.9 to 3.7) than in the rice bread (3.1), except for the white CMSS005 that did not differ from that sample. This descriptor was scored higher for bronze and brown BRS 305 breads in contrast to white CMSS005 and commercial sorghum breads.

The two terms differing among the samples for the flavor category, 'bitter taste' and 'astringency', were also perceived by assessors as relatively weak, with values up to 2.3 on a 9 cm scale. Except for the 1167048 sample, commercial sorghum bread was rated as more bitter than all other breads, which was also observed for this attribute in

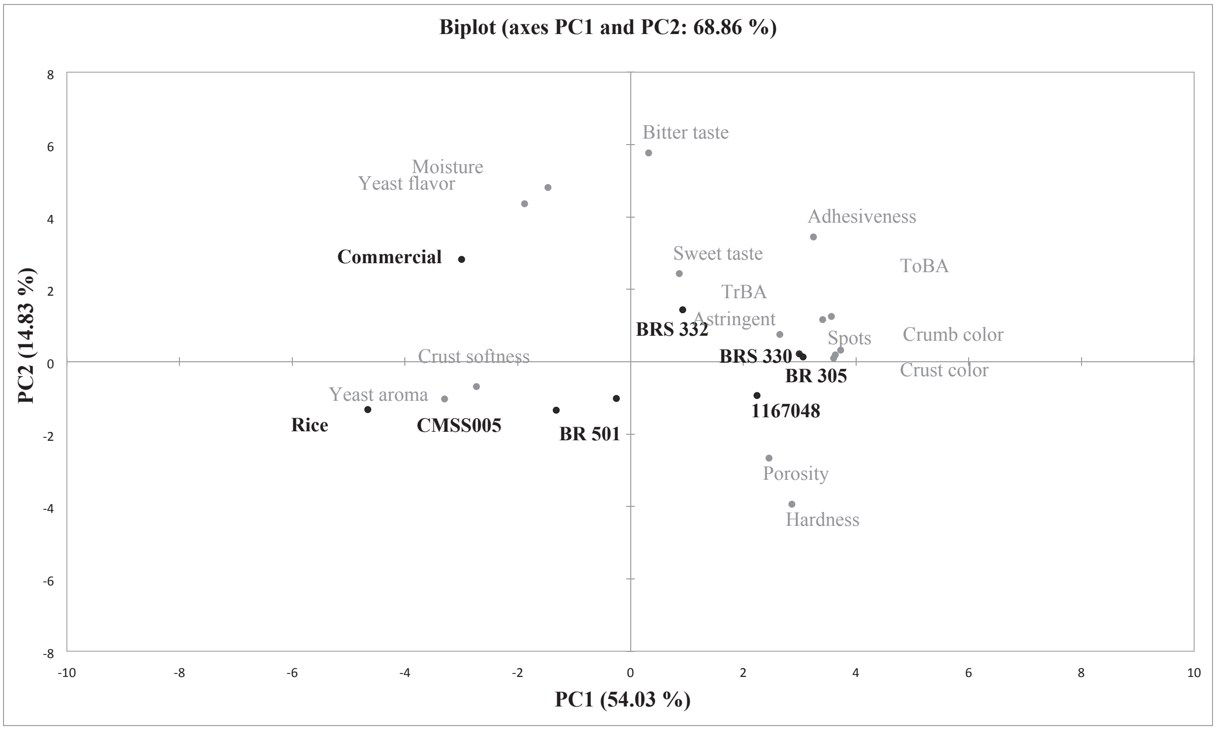

Fig. 3. Principal Component Analysis on ODP data (n = 18), with variables and observations. Rice: rice bread; Commercial: commercial white sorghum bread; 1167048: brown 1167048 sorghum bread; BR 305: brown BR 305 sorghum bread; BRS 330: bronze BRS330 sorghum bread; BRS 332: bronze BRS 332 sorghum bread; CMSS005: white CMSS005 sorghum bread; BR 501: white BR 501 sorghum bread. TrBA: Traditional bread aroma, ToBA: Toasted bread aroma.

CATA. Moreover, the other traditional sample (rice bread) presented the lowest score for the descriptor 'astringency', differing from all samples except BRS 332 sorghum bread. In one more parallel, this descriptor did not differ among samples in CATA, but it was likewise scarcely checked.

Finally, the category texture had one term, 'adhesiveness', perceived as different among the samples. This term refers to the ability of food to adhere to the teeth when chewed, and was significantly higher for bronze and brown sorghum breads (4.8–5.2) than for white sorghum (3.8 for either bread) and rice (3.1) breads. Commercial sorghum bread did not differ from bronze and brown samples and scored higher for this attribute than the rice bread.

PCA was performed on ODP data, accounting for 68.9% of original variance on the first two components (Fig. 3). According to Fig. 3, both traditional breads presented a distinct sensory profile when compared to selected sorghum breads, with rice bread spatially closer to white than colored sorghum breads. Among the selected sorghum breads, white breads were more sensorially associated between them than from bronze and brown genotypes. PC1 explained 54% of total variance and showed the spatial separation of traditional and white sorghum breads in the negative side, and bronze and brown breads in the positive side (Fig. 3). The first principal component had a greater association with descriptors 'yeast aroma', 'crust softness' (third quadrant), 'spots', 'crumb color', 'crust color', 'traditional bread aroma' and 'toasted bread aroma' (first quadrant, Fig. 3). Indeed, traditional samples were characterized by higher yeast aroma and crust softness intensity, having the lowest intensity in color and remaining aroma (bread and toasted bread) attributes, while the colored sorghum breads presented an opposite intensity of such descriptors, explaining their localization at the opposite side in PC1. Furthermore, bronze BRS 330 was characterized as having more intense crumb and crust colors and less intense crust softness than BRS 332, which also differed in these descriptors from white sorghum breads, explaining in part their intermediate localization between these groups of samples. Brown 1167048 was less associated with their BR 305 counterpart presenting less intense 'crust color' and more intense 'spots' than that sample.

PC2 explained 14.8% of data variance and was positively related to 'bitter taste', 'moisture', 'yeast flavor' and 'adhesiveness' and negatively related to 'porosity' and 'hardness' (Fig. 3). This component showed the spatial separation of commercial white sorghum bread in the positive side of the component (second quadrant), distant from rice bread (third quadrant), and explained the localization of bronze BRS 332 sorghum bread in more positive values than bronze BRS 330 and brown BR 305, which were more distanced from brown 1167048 loaded on negative values (fourth quadrant). Rice bread was more characterized by its lower 'porosity' and 'adhesiveness', being less associated with commercial sorghum sample in the latter descriptor. 'Bitter taste' located in positive extremity also characterized traditional breads. Moreover, 'porosity' likewise characterized brown 1167048 as opposed to brown BR 305 bread.

Therefore, although the sample distribution on bi-dimensional plots was consistent between CATA and ODP, the attributes used to characterize the samples (those located near a given bread in graphs) were generally different. Exception was the attribute 'dark crust' in CA, equivalent to 'crust color' in PCA, nearby brown BR 305 and bronze BRS 330 breads.

3.3. Comparison between CATA and ODP

The use of sample configurations to calculate the RV coefficient has been recognized as a simple way to verify the similarity between two data sets, and could provide support for the inferences above on the similar sample distributions noticed for CATA and ODP (Escoufier & Robert, 1976). Remarkably, a RV coefficient of 0.925 ($p < 0.002$) was found, corroborating the pronounced degree of similarity and significance between CATA and ODP on sample differentiation. It is worth noting that, by assessing the RV coefficient between sample configurations, one can conclude that samples were similarly differentiated from each other for both methods, but this not necessarily means that they were differentiated regarding the same attributes. Indeed, in our work, different groups of assessors performed the attribute elicitation for either method. Terms elicited in CATA by the Repertory Grid method were afterwards presented to ODP assessors in order to choose those that they considered critical to describe the samples. ODP assessors proposed slight changes in the descriptive terms to fit them in a rating scale, for instance by using 'porosity' in replacement of alveoli-related terms. Therefore, although the set of descriptive terms were not the same for the two methods, making unfeasible the calculation of the RV coefficient for attribute configurations, ODP attributes were derived from CATA's being very similar among them.

Another criterion to assess the similarity between methods is the comparison of the graphical representation of their descriptive data (Aguiar et al., 2018). In this study, the spatial distribution of samples found in PCA for the ODP data (Fig. 3) resembles that found in CA for the CATA data (Fig. 2), especially for bronze and brown sorghum breads. However, in ODP the commercial sorghum bread is separated from the other samples in a map quadrant whereas the rice bread is closer to selected white sorghum breads, in contrast to the CATA map, in which the commercial sorghum bread is closer to selected white sorghum samples while shares the same quadrant with the rice bread. This fact is likely related to the intrinsic characteristics of each method. Checking and rating/quantifying are different ways of analyzing a sensation or attribute and have an influence on method sensibility. Moreover, semi-trained panels are more familiarized with the samples and the attributes, and by interacting with references, they are more aware of the perceived sensation. In fact, 50% of the attributes included in CATA question were found to be non-significant for discriminating the samples in the present study, against 26.7% of non-significant attributes found for ODP. For instance, when similar or corresponding attributes of both methods are compared side by side, one can see that 'yeast aroma', 'astringency' and the related 'adhesiveness' and 'sticking in the roof of your mouth' were not discriminative in CATA analysis (Table 2) but they were indeed perceived as different among the samples in ODP (Table 3). Conversely, regardless the method, attributes 'sweet taste' and 'yeast flavor' presented no significant differences among the samples, whereas 'bitterness' discriminated them in a similar way.

A limitation of investigations that compare methodologies based on sensory evaluations conducted by semi-trained and untrained assessors lies precisely in the bias or source of variation deriving out of the use of different groups of individuals. This procedure is inevitable since the number of evaluators required for each method is quite different, as for CATA and ODP". Ares, Tárrega, Izquierdo, and Jaeger (2014) investigated the number of consumers necessary to obtain stable sample and descriptor configurations from CATA questions and concluded that the minimum recommendation is 60–80 consumers. However, according to Hough et al. (2006), 112 consumers are necessary for acceptability tests, and since CATA question was applied in the same paper ballot where liking was rated, this was the minimum number considered in our study. For ODP, on the other hand, the minimum number of semi-trained assessors necessary is 16 people, as aforementioned (Silva et al., 2014). In our study, 124 consumers and 18 semi-trained assessors evaluated the samples using CATA and ODP, respectively. In the same way that occurred with other studies found in the literature that compared two or more methods using different sensory panels (e.g. Dooley et al., 2010; Silva et al., 2013; Ares et al., 2015), this variation was contemplated within the random error (in the statistical residue) as it consists of a source of variation that we cannot control. Nonetheless, all the other sources of variation of our investigation related to samples and judges were controlled, as previously described.

3.4. Consumer acceptance

All breads scored higher than 6 ("liked slightly" in hedonic scale) for all individual acceptance attributes evaluated (Table 4). For appearance, rice bread was more accepted than all selected sorghum breads with exception to the bronze BRS 332. Bronze BRS 332, bronze BR 330 and white BR 501 were the most accepted samples by consumers in terms of flavor, whereas samples were equally accepted in both aroma and texture attributes.

Table 4
Acceptance of gluten-free breads using a 9-point hedonic structured scale (n = 124).

Bread samples	Appearance	Aroma	Flavor	Texture	Overall liking
Rice	7.9 ^{a}	6.6	6.6 ^{bcd}	6.8	6.8 ^{bc}
Commercial	7.7 ^{ab}	6.4	6.1 ^{d}	6.7	6.6 ^{bc}
CMSS005	7.0 ^{d}	6.5	6.4 ^{cd}	6.6	6.5^{c}
BR 501	7.3 ^{cd}	6.6	6.9 ^{abc}	6.7	6.9 ^{abc}
BRS 330	7.4 ^{bcd}	6.8	6.9 ^{ab}	7.0	7.0 ^{ab}
BRS 332	7.6 ^{abc}	6.9	7.2 ^{a}	7.0	7.3 ^{a}
1167048	7.3 ^{bcd}	6.6	6.6 ^{bcd}	6.8	6.8 ^{bc}
BR 305	7.1 ^{d}	6.8	6.6 ^{bc}	6.6	6.8 ^{bc}
p-value (ANOVA)	0.001	0.213	0.001	0.500	0.016

Different letters in the same column indicate significant difference (Fisher test, $p < 0.05$). Rice: rice bread; Commercial: commercial white sorghum bread; 1167048: brown 1167048 sorghum bread; BR 305: brown BR 305 sorghum bread; BRS 330: bronze BRS 330 sorghum bread; BRS 332: bronze BRS 332 sorghum bread; CMSS005: white CMSS005 sorghum bread; BR 501: white BR 501 sorghum bread.

As for individual attributes, all breads evaluated in this study were globally liked for consumers given their mean scores within the acceptance region of the scale. Bronze BRS 332, bronze BRS 330 and white BR 501 sorghum breads exhibited the highest mean scores for overall liking, not differing among themselves. The same sorghum breads presented the more accepted flavor as aforementioned. Nonetheless, bronze BRS 332 with a mean score of 7.3 (between hedonic terms "liked moderately" and "liked very much") was more accepted than white CMSS005 and both brown and traditional breads, whereas bronze BRS 330 and white BR 305 did not differ from other samples.

Besides the assessment of overall acceptance considering the total group of consumers (n = 124), cluster analysis was applied to hedonic scores and enabled the identification of two consumer segments with different acceptance profiles (Table 5). Cluster 1 (n = 42, 34%) was composed by consumers who generally attributed to samples scores of indifference in terms of liking ("neither like or dislike"). The most accepted breads for these consumers were the bronze and brown ones, while only the bronze BRS 330 bread differing from all the white sorghum and traditional samples. Cluster 2 accounted for the majority of the evaluators (n = 82, 66%), which had more positive hedonic perception of breads in comparison to cluster 1, with mean liking scores exceeding 7 for all samples. Bronze BRS 332, white BR 501 and rice were the most accepted breads, but the latter did not differ from any sample. Brown and bronze BRS 330 breads were among the highest liking scores in cluster 1 and among the least liked samples as assessed by consumers of cluster 2 (Table 5). Despite the evident difference in the acceptance pattern between the clusters (*t* test, $p < 0.05$), both consumer segments indicated the bronze BRS 332 sorghum bread among the most accepted samples and white CMSS005 and commercial white sorghum among the least accepted samples.

Consumers participating in acceptance testing were predominantly female and about the half part of individuals aged between 26 and 55 years old, regardless the cluster (Table 5). The difference between the consumer segments was the number of evaluators aged between 18 and 25 years old, three times the number of those with more than 56 years in cluster 1, and 8% lower than the number of these individuals in cluster 2, likely suggesting that older subjects contributed for more positive hedonic responses.

3.4.1. Drivers of liking

Consumers in CATA and semi-trained assessors in ODP separated bread samples following a similar distribution pattern (Figs. 2 and 3,

Table 5
Overall acceptance at the general level and for consumer segments, and their demographic profiles.

		Cluster 1 (n = 42)	Cluster 2 (n = 82)	General (n = 124)
Overall liking*	Rice	5.3 [bcB]	7.5 [abcA]	6.8 [bc]
	Commercial	4.9 [cB]	7.4[bcA]	6.6 [bc]
	CMSS005	5.0 [cB]	7.3 [cA]	6.5[c]
	BR 501	5.4 [bcB]	7.7 [abA]	6.9 [abc]
	BRS 330	6.2 [aB]	7.4 [bcA]	7.0 [ab]
	BRS 332	6.1 [abB]	7.9 [aA]	7.3 [a]
	1167048	5.7 [abB]	7.3 [cA]	6.8 [bc]
	BR 305	5.9 [abB]	7.2 [cA]	6.8 [bc]
Gender**	Male	31	39	36
	Female	69	61	64
Age**	18–25 y old	36	23	27
	26-55y old	52	46	48
	> 56 y old	12	31	25
Consumption of conventional breads**	Regular users	88	85	86
	Light users	10	12	11
	Non-users	2	2	2
Consumption of whole breads**	Regular users	69	78	75
	Light users	26	18	21
	Non-users	5	4	4
Consumption of gluten-free breads**	Regular users	38	40	40
	Non-users	62	60	60

* Mean overall liking scores from acceptance testing.

** Demographic profile data expressed in percentage of total individuals. Cluster 1 and cluster 2 refer to the two consumer segments identified in Cluster Analysis. Different lowercase letters in the same column indicate significant difference (Fisher test, $p < 0.05$). Different capital letters in the same row indicate significant difference between clusters (Student's *t*-test, $p < 0.05$). Regular users: individuals that used to consume bread once or more than once in a month or in a trimester. Light users: individuals whose consumption frequency was equal or more than once in a semester. Non-users: individuals who did not consume the type of bread. Within the categories considering the consumption of conventional and whole breads, absence of consumption was reported for about 2 to 5% of consumers, but these individuals reported the consumption of gluten-free bread, so they remained in the study. Sensory tests were carried out in central places where people usually go to buy gluten-free and whole breads, to better represent the potential consumers of the type of product being developed. Rice: rice bread; Commercial: commercial white sorghum bread; 1167048: brown 1167048 sorghum bread; BR 305: brown BR 305 sorghum bread; BRS 330: bronze BRS 330 sorghum bread; BRS 332: bronze BRS 332 sorghum bread; CMSS005: white CMSS005 sorghum bread; BR 501: white BR 501 sorghum bread.

RV = 0.92), but using generally different attributes. The impact of these attributes on overall acceptance was assessed for both methods to identify whether and how they drive consumer liking. Ten attributes with significant positive impact on acceptance (desirable in breads, driving their liking) were identified in CATA (Fig. 4), and included 'soft aroma', crust and crumb characteristics (soft and thin and soft, mushy and moist, respectively), 'neutral flavor', 'appearance of whole flour breads', and 'uniform alveoli'. The two latter were different among the samples ($p < 0.05$, Table 2). On the other hand, 'irregular alveoli', 'hard crust', 'grainy texture' and 'raw bread aroma' presented negative influence on bread acceptance. In ODP, five out of the 15 attributes evaluated presented significant influence on acceptance, being four identified as drivers of liking: 'crumb color', 'crust color', 'spots' and 'traditional bread aroma' (Fig. 5). 'Crust softness' was the only driver of disliking identified in ODP, while the corresponding attribute 'soft crust' was identified as driving the consumer liking in CATA. 'Crust softness' was located at the extremity of the PC1 (PCA, Fig. 3), and samples were differently distributed according to their different intensities for this attribute, whereas 'soft crust' was equally used to describe all samples, being relatively little checked (Table 2). In fact,

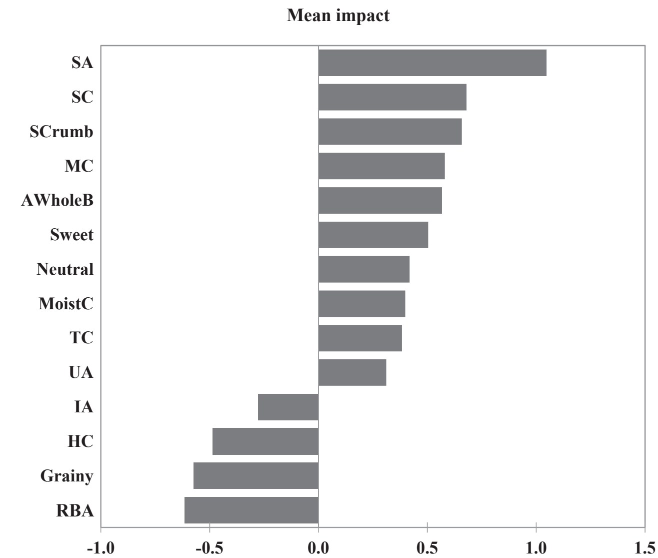

Fig. 4. Mean impact of attributes evaluated in CATA with significant influence on overall acceptance (n = 124). SA: soft aroma, SC: soft crust, SCrumb: soft crumb, MC: mushy crumb, AWholeB: appearance of whole flour breads, MoistC: moist crumb, TC: thin crust, UA: uniform alveoli, IA: irregular alveoli, HC: hard crust, RBA: raw bread aroma.

distinct drivers of liking and disliking were identified depending on the method employed, i.e., whether the sensory description of samples was provided by consumers or semi-trained assessors. Similar observation was reported by Mello et al. (2019) comparing CATA and QDA.

4. Conclusion

In summary, the two rapid techniques effectively described and discriminated the breads, providing corresponding pattern of sample distribution on sensory maps. This similarity was confirmed by an elevated and significant RV coefficient. In spite of that, overall samples were characterized using different attributes and distinct drivers of liking were identified. Drivers of liking identified through CATA included 'appearance of whole flour breads', 'neutral flavor', 'uniform alveoli', and 'soft crust', whereas ODP indicated the positive impact of 'crumb color', 'crust color', 'spots' and 'traditional bread aroma' on consumer acceptance. The differences of method sensitivities, the way sensory terms are presented in the paper ballots (check-list or an intensity scale) as well as the degree of familiarity of the panel with samples or references are the basic explanations underlying the variation in the drives of liking identified by CATA and ODP.

Gluten-free bread formulations were successfully developed and accepted by consumers, being those breads prepared with selected sorghum genotypes generally more accepted than those prepared with commercial flours (sorghum and rice). The BRS 332 bread was among the most accepted samples from either cluster of consumers, and was characterized by the descriptors 'caramel color', 'appearance of whole flour breads' and 'soft aroma', and by lower 'raw bread aroma' in CATA. In ODP, this sample was characterized by intermediate crumb and crust color compared to white and brown breads, and by relatively high scores of 'porosity', 'adhesiveness', 'traditional bread aroma' and 'moisture'. Further studies are warranted to determine the chemical composition of these grains and their relation with desired technological and sensory properties of the product. This information could prove useful to investigators in the formulation design of gluten-free products for this demanded market and guide plant breeders in the development of new genotypes attaining desirable attributes driven by consumer hedonic responses.

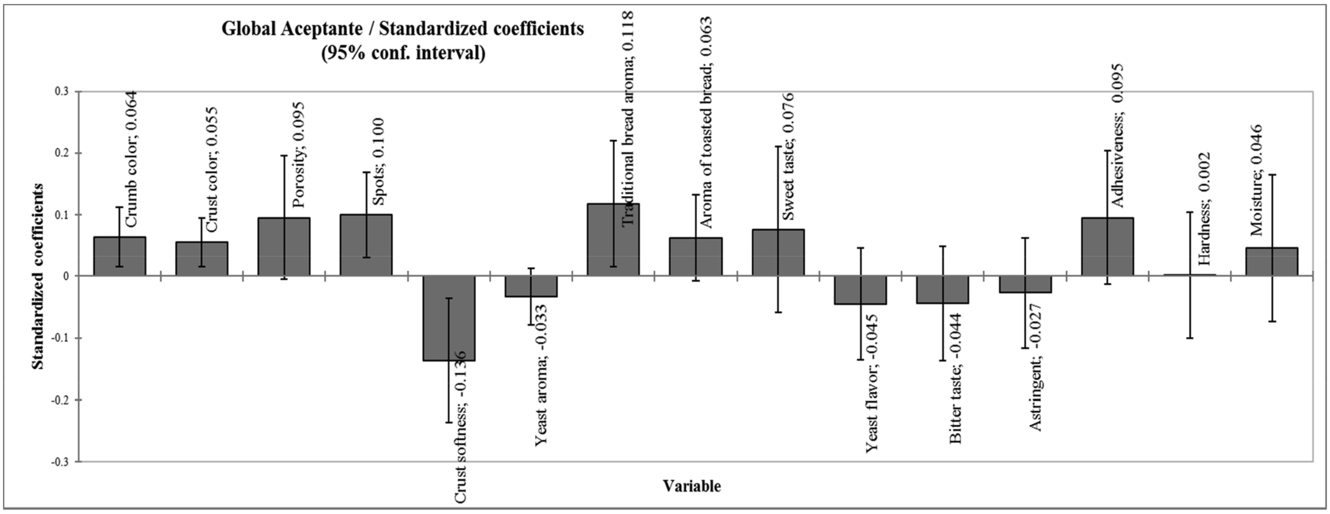

Fig. 5. Graphical representation of PLS analysis with standardized coefficients correlating descriptive (ODP) and acceptance data (9-point hedonic scale).

Acknowledgments

Brazilian agencies CAPES (PNPD grant for D.B.R.), CNPq and FAP-DF are acknowledged for their financial support.

Declaration of Competing Interest

Authors declare that there is no conflict of interest regarding the publication of this article. Declarations of interest: none.

Author contributions

All authors of this manuscript have directly participated in the execution of the study. Conceived and designed the experiments: L.A.A., L.L.O., L.M., V.A.V.Q. Performed the experiments: L.A.A. Analyzed the data: D.B.R., L.A.A., L.L.O., L.M. Wrote the paper: D.B.R., L.A.A., L.L.O. All authors read and approved the final manuscript.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodres.2020.108999.

References

Adams, J., Williams, A., Lancaster, B., & Foley, M. (2007). Advantages and uses of check-all-that-apply response compared to traditional scaling of attributes for salty snacks. In Conference paper at the 7th Pangborn sensory science symposium. Minneapolis, MN, USA.

Aguiar, L. A., Melo, L., & de Oliveira, L. de L. (2018). Validation of rapid descriptive sensory methods against conventional descriptive analyses: A systematic review. *Critical Reviews in Food Science and Nutrition, 3*, 1–18.

Ares, G., Antúnez, L., Bruzzone, F., Vidal, L., Giménez, A., Pineau, B., ... Jaegerb, S. R. (2015). Comparison of sensory product profiles generated by trained assessors and consumers using CATA questions: Four case studies with complex and/or similar samples. *Food Quality and Preference, 45*, 75–86.

Ares, G., Tárrega, A., Izquierdo, L., & Jaeger, S. R. (2014). Investigation of the number of consumers necessary to obtain stable sample and descriptor configurations from check-all-that-apply (CATA) questions. *Food Quality and Preference, 31*, 135–141.

Ares, G., & Varela, P. (2014). Comparison of novel methodologies for sensory characterization. In P. Varela, & G. Ares (Eds.). *Novel techniques in sensory characterization and consumer profiling* (pp. 365–390). Boca Raton: CRC Press.

Ares, G., & Varela, P. (2018). Consumer-based methodologies for sensory characterization. In G. Ares, & P. Varela (Eds.). *Methods in consumer research: New approaches to classic methods* (pp. 187–209). Cambridge: Woodhead Publishing.

Awika, J. M., Rooney, L. W., Wu, X., Prior, R. L., & Cisneros-Zevallos, L. (2003). Screening methods to measure antioxidant activity of sorghum (*Sorghum bicolor*) and sorghum products. *Journal of Agricultural and Food Chemistry, 51*, 6657–6662.

Caporale, G., Policastro, S., Carlucci, A., & Monteleone, E. (2006). Consumer expectations for sensory properties in virgin olive oils. *Food Quality and Preference, 17*, 116–125.

Ciacci, C., Maiuri, L., Caporaso, N., Bucci, C., Del Giudice, L., Rita Massardo, D., ... Londei, M. (2007). Celiac disease: *In vitro* and *in vivo* safety and palatability of wheat-free sorghum food products. *Clinical Nutrition, 26*, 799–805.

Dykes, L., Rooney, L. W., Waniska, R. D., & Rooney, W. L. (2005). Phenolic compounds and antioxidant activity of sorghum grains of varying genotypes. *Journal of Agricultural and Food Chemistry, 53*, 6813–6818.

Dooley, L., Lee, Y. S., & Meullenet, J. F. (2010). The application of check-all-that-apply (CATA) consumer profiling to preference mapping of vanilla ice cream and its comparison to classical external preference mapping. *Food Quality and Preference, 21*, 394–401.

Delgado, C., & Guinard, J.-X. (2011). How do consumer hedonic ratings for extra virgin olive oil relate to quality ratings by experts and descriptive analysis ratings? *Food Quality and Preference, 22*, 213–225.

Food and Agriculture Organization of the United Nations. FAOSTAT. (2017). http://www.fao.org/faostat/en/#data/QC Accessed 10 June 2019.

Guinard, J.-X., Uotani, B., & Schlich, P. (2001). Internal and external mapping of preferences for commercial lager beers: Comparison of hedonic ratings by consumers blind versus with knowledge of brand and price. *Food Quality and Preference, 12*, 243–255.

Hadebe, S. T., Modi, A. T., & Mabhaudhi, T. (2017). Drought tolerance and water use of cereal crops: A focus on sorghum as a food security crop in Sub-Saharan Africa. *Journal of Agronomy and Crop Science, 203*, 177–191.

Hough, G., Wakeling, I., Mucci, A., Chambers, E., Gallardo, I. V., & Alves, L. R. (2006). Number of consumers necessary for sensory acceptability tests. *Food Quality and Preference, 17*, 522–526.

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)/Food and Agriculture Organization (FAO). 2004. Sorghum, a crop of substance. Patancheru: International Crops Research Institute for the Semi-Arid Tropics.

Ishii, R., Chang, H., & O'Mahony, M. (2007). A comparison of serial monadic and attribute-by-attribute protocols for simple descriptive analysis with untrained judges. *Food Quality and Preference, 18*, 440–449.

Labbe, D., Ritz, A., & Hugi, A. (2004). Training is a critical step to obtain reliable product profiles in a real food industry context. *Food Quality and Preference, 15*, 341–348.

Martino, H. S. D., Tomaz, P. A., Moraes, E. A., Conceição, L. L., Oliveira, D. S., Queiroz, V. A. V., ... Ribeiro, S. M. R. (2012). Chemical characterization and size distribution of sorghum genotypes for human consumption. *Revista do Instituto Adolpho Lutz, 71*, 337–344.

Meilgaard, M. C., Civille, G. V., & Carr, B. T. (2006). *Sensory evaluation techniques* (4th ed.). Boca Raton: CRC Press.

Meyners, M., Castura, J. C., & Carr, B. T. (2013). Existing and new approaches for the analysis of CATA data. *Food Quality and Preference, 30*, 309–319.

Mello, L. S. S., Almeida, E. L., & Melo, L. (2019). Discrimination of sensory attributes by trained assessors and consumers in semi-sweet hard dough biscuits and their drivers of liking and disliking. *Food Research International, 12*, 599–609.

Minim, V. P. R., & Silva, R. C. S. N. (Eds.). (2016). *Análise sensorial descritiva*. Viçosa: UFV.

Moskowitz, H. R. (1983). *Product testing and sensory evaluation of foods.* Westport: Food and Nutrition Press.

Pineli, L. de L. de O., Zandonadi, R. P., Botelho, R. B. A., de Oliveira, V. R., & Figueiredo, L. F. de A. (2015). The use of sorghum to produce gluten-free breads: A systematic review. *Journal of Advanced Nutrition and Human Metabolism, 2*, 944.

Pontieri, P., Mamone, G., De Caro, S., Tuinstra, M. R., Roemer, E., Okot, J., ... Del Giudice, L. (2013). Sorghum, a healthy and gluten-free food for celiac patients as demonstrated by genome, biochemical and immunochemical analyses. *Journal of Agricultural and Food Chemistry, 61*, 2565–2571.

Queiroz, V. A. V., Carneiro, H. L., Deliza, R., Rodrigues, J. A. S., Vasconcellos, J. H., Tardin, F. D., & Queiroz, L. R. (2011). Genótipos de sorgo para produção de barra de cereais. *Pesquisa Agropecuária Brasileira, 47*, 287–293.

Robert, P., & Escoufier, Y. (1976). A unifying tool for linear multivariate statistical methods: The RV-Coefficient. *Journal of the Royal Statistical Society, 25*(3), 257–265.

https://doi.org/10.2307/2347233.

Schober, T. J., Messerschmidt, M., Bean, S. R., Park, S.-H., & Arendt, E. K. (2005). Gluten-free bread from sorghum: Quality differences among hybrids. *Cereal Chemistry, 82*, 394–404.

Silva, R. C. S. N., Minim, V. P. R., Simiqueli, A. A., Moraes, L. E. S., Gomide, A. I., & Minim, L. A. (2012). Optimized Descriptive Profile: A rapid methodology for sensory description. *Food Quality and Preference, 24*, 190–200.

Silva, R. C. S. N., Minim, V. P. R., Carneiro, J. D. S., Nascimento, M., Lucia, S. M. D., & Minim, L. A. (2013). Quantitative sensory description using the Optimized Descriptive Profile: Comparison with conventional and alternative methods for evaluation of chocolate. *Food Quality and Preference, 30*, 169–179.

Silva, R. C. S. N., Minim, V. P. R., Silva, A. N., Peternelli, L. A., & Minim, L. A. (2014). Optimized Descriptive Profile: How many judges are necessary? *Food Quality and Preference, 36*, 3–11.

Stefoska-Needham, A., Beck, E. J., Johnson, S. K., & Tapsell, L. C. (2015). Sorghum: An underutilized cereal whole grain with the potential to assist in the prevention of chronic disease. *Food Reviews International, 31*, 401–437.

Stone, H., Bleibaum, R., & Thomas, H. (2012). *Sensory evaluation practices* (4th ed.). Cambridge: Academic Press.

Taylor, J. R. N., Schober, T. J., & Bean, S. R. (2006). Novel food and non-food uses for sorghum and millets. *Journal of Cereal Sciences, 44*, 252–271.

Tenenhaus, M., Pages, J., Ambroisini, L., & Guinot, C. (2005). PLS methodology to study relationships between hedonic judgements and product characteristics. *Food Quality and Preference, 16*, 315–325.

Tuinstra, M. R. (2008). Food-grade sorghum varieties and production considerations: A review. *Journal of Plant Interactions, 3*(1), 69–72. https://doi.org/10.1080/17429140701722770.

Varela, P., & Ares, G. (2012). Sensory profiling the blurred line between sensory and consumer science. A review of novel methods for product characterization. *Food Research International, 48*, 893–908.

Visarada, K. B. R. S., & Aruna, C. (2019). Sorghum: A bundle of opportunities in the 21st century. In C. Aruna, K. B. R. S. Visarada, B. Venkatesh Bhat, & V. A. Tonapi (Eds.). *Breeding sorghum for diverse end uses* (pp. 1–14). Cambridge: Woodhead Publishing.

Worch, T., & Piqueras-Fiszman, B. (2015). Contributions to assess the reproducibility and the agreement of respondents in CATA tasks. *Food Quality and Preference, 40*, 137–146.