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PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIA E TECNOLOGIA DE ALIMENTOS

TESE

Elaboração e caracterização físico-química e sensorial de cereal matinal de sorgo por extrusão

Davy William Hidalgo Chávez

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ELABORAÇÃO E CARACTERIZAÇÃO FÍSICO-QUÍMICA E SENSORIAL DE CEREAL MATINAL DE SORGO POR EXTRUSÃO

DAVY WILLIAM HIDALGO CHÁVEZ

Sob a Orientação de
José Luis Ramírez Ascheri, D.Sc

e Co-orientação de
Carlos Wanderlei Piler de Carvalho, PhD

Tese submetida como requisito para obtenção do grau de **Doutor em Ciência e tecnologia de Alimentos** no Curso de Pós-Graduação em Ciência e Tecnologia de Alimentos, Área de concentração em

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DAVY WILLIAM HIDALGO CHAVEZ

Tese submetida como requisito parcial para obtenção do grau de **Doutor em Ciências e Tecnologia de Alimentos**, no Programa de Pós-Graduação em Ciência e Tecnologia de Alimentos, área de concentração em Tecnologia de Alimentos.

TESE APROVADA EM 26/07/2018

Dr. CARLOS WANDERLEI PILER DE CARVALHO, EMBRAPA
(Co-Orientador)

Dr. EDWIN ELARD GARCIA ROJAS, UFF
(Examinador interno)

Dr. FELIX EMÍLIO PRADO CORNEJO, EMBRAPA
(Examinador externo)

Dr. SIDNEY PACHECO, EMBRAPA
(Examinador externo)

Dr. ROSIRES DELIZA, EMBRAPA
(Examinador interno)

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RESUMO

HIDALGO-CHÁVEZ, Davy William. **Elaboração e caracterização físico-química e sensorial de cereal matinal de sorgo por extrusão. 98 p.** Tese (Doutorado em Ciência de Alimentos). Instituto de Tecnologia, Departamento de Tecnologia de Alimentos, Universidade Federal Rural do Rio de Janeiro, Seropédica, Rio de Julho, 2018.

O grão inteiro de sorgo tem sido considerado um alimento com propriedades funcionais, pois possui altos conteúdos de compostos bioativos, como fibra alimentar e fitoquímicos, com maior capacidade antioxidante do que outros cereais. Ele apresenta grande variabilidade genética apresentando grãos de cores e tamanhos variados, os quais vêm sendo estudados quanto as suas qualidades funcionais e aceitação sensorial. Desta forma, o presente trabalho teve como objetivo desenvolver cereais matinais integrais partir de grãs inteiros de seis genótipos de sorgo de diferentes cores de pericarpo, formato e composição química. O estudo foi dividido em quatro capítulos. No capítulo 1, foi realizada uma revisão bibliográfica sobre o uso de sorgo como cereal alternativo ao consumo de glúten, produtos sem glúten e estudos sensoriais. Os resultados demonstraram que poucos estudos sensoriais foram conduzidos sobre o desenvolvimento de novos produtos a base de sorgo, que podem ter sido responsáveis pela baixa disponibilidade comercial de produtos de sorgo, sendo proposto o uso do sorgo em sua forma integral como alternativa para produtos sem glúten, bem como verificou-se a necessidade de mais estudos sensoriais para o desenvolvimento de produto livres de glúten de boa aceitabilidade. No capítulo 2, os seis genótipos de sorgo, BR305 e SC319 (sorgo com tanino), BRS373 e BRS330 (pericarpo vermelho sem tanino) e BRS501 e CMSS005 (pericarpo branco sem tanino), foram analisados quanto a morfologia do grão inteiro, a capacidade antioxidante da farinha integral, bem como a extrusão termoplástica foi utilizada para obtenção de cereal matinal cujos produtos foram avaliados quanto a aceitação sensorial. Observou-se que o sorgo com tanino apresentou maior propriedade antioxidante (BR305 apresentou composto fenólico total de 16,06 mg/100g e tanino condensado de 4,39 mg/100g). Por outro lado, sorgo com tanino, apresentou menor aceitação sensorial em contraste com os genótipos de sorgo de baixo teor de tanino, os quais apresentaram maior aceitação. Em função deste resultado, foi proposto no capítulo 3 a mistura de dois genótipos de sorgo com e sem tanino, BR305 e BRS373, de forma a combinar o maior teor de capacidade antioxidante com o maior sorgo de maior aceitação sensorial usando um delineamento de mistura. Neste experimento foi considerada a adição de açúcar na mistura de forma a obter cereal matinal doces, bem como para avaliar o efeito da presença do mesmo nas propriedades funcionais e aceitação sensorial. Os resultados indicaram que a mistura de 45% de sorgo com tanino, 45% de sorgo sem tanino e 10% de açúcar apresentou considerável propriedade antioxidante, bem como boa aceitação sensorial. Finalmente, no capítulo 4 foi desenvolvida uma nova metodologia para determinação do tempo de tigela (tempo de mudança de textura do cereal imerso em meio líquido), onde foram comparadas a análise instrumental e sensorial da textura usando o modelo matemático proposto por Weibull. Como resultado foram propostas duas novas metodologias para a determinação do tempo de tigela: (i) tempo médio de tigela instrumental $IBT_{(1/2)}$, indicado quando o objetivo é utilizar uma metodologia rápida de comparação de amostras, e (ii) tempo médio de tigela sensorial $SBT_{(1/2)}$, este indicado quando o objetivo é prever o tempo real após o qual, a amostra é rejeitada.

Palavras chave: Cozimento por extrusão, sorgo com tanino, modelo de Weibull.

ABSTRACT

HIDALGO-CHÁVEZ, Davy William. **Elaboration, physicochemical and sensory characterization of whole grain sorghum breakfast cereal by extrusion. 2018. 98 p.** Thesis (Doctor in Food Science). Instituto de Tecnologia, Departamento de Tecnologia de Alimentos, Universidade Federal Rural do Rio de Janeiro, Seropédica, Rio de Julho, 2018.

The whole grain of sorghum has been considered a food with functional properties, since it has high contents of bioactive compounds, like alimentary fiber and phytochemicals, with greater antioxidant capacity than other cereals. It presents great genetic variability presenting grains of varied colors and sizes, which have been studied for their functional qualities and sensorial acceptance. In this way, the present work aimed to develop whole breakfast cereal from whole grains of six sorghum genotypes of different colors of pericarp, shape and chemical composition. The study was divided into four chapters. In Chapter 1, a literature review was carried out on the use of sorghum as an alternative cereal to the consumption of gluten, gluten-free products and sensory studies. The results showed that few sensorial studies were conducted on the development of new sorghum products, which may have been responsible for the low commercial availability of sorghum products, and it is proposed to use sorghum in its integral form as an alternative to gluten-free products, as well as the need for more sensory studies for the development of gluten-free products of good acceptability. In Chapter 2, the six genotypes of sorghum, BR305 and SC319 (tannin sorghum), BRS373 and BRS330 (red pericarp without tannin) and BRS501 and CMSS005 (white pericarp without tannin) were analyzed for whole grain morphology, antioxidant of the whole meal, as well as the thermoplastic extrusion was used to obtain morning cereal whose products were evaluated for sensorial acceptance. It was observed that the sorghum with tannin presented higher antioxidant properties (BR305 presented total phenolic compound of 16.06 mg / 100g and condensed tannin of 4.39 mg / 100g). On the other hand, sorghum with tannin presented lower sensory acceptance in contrast to the low tannin sorghum genotypes, which presented greater acceptance. As a result of this result, a mixture of two sorghum genotypes with and without tannin, BR305 and BRS373, was proposed in order to combine the highest antioxidant capacity content with the highest sorghum of higher sensorial acceptance using a mixture design. In this experiment it was considered the addition of sugar in the mixture in order to obtain a sweet breakfast cereal, as well as to evaluate the effect of the presence of the same on the functional properties and sensorial acceptance. The results indicated that the mixture of 45% of sorghum with tannin, 45% of sorghum without tannin and 10% of sugar presented considerable antioxidant properties as well as good sensory acceptance. Finally, in chapter 4 a new methodology was developed to determine the time of the bowl (time of change of the texture of the cereal immersed in liquid medium), where we compared the instrumental and sensorial analysis of the texture using the mathematical model proposed by Weibull. As a result, two new methodologies were proposed for the determination of bowl time: (i) IBT instrumental half bowl time $_{(1/2)}$, indicated when the objective is to use a rapid sample comparison methodology, and (ii) SBT for sensory half bowl time $_{(1/2)}$, this is indicated when the goal is to predict the real time after which, the sample is rejected.

Keyword: Extrusion cooking, tannin sorghum, Weibull model.

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LIST OF ABBREVIATIONS AND SYMBOLS

a*	Red/green coordinate
ABTS	2,2'-azinobis, 3-etilbenzotiazolina-6-ácido sulfônico Association of
AOAC	Official Agricultural Chemists
Axy	XY plane Area
Axz	Area in XZ plane '
b*	Yellow/blue coordinate
BD	Bulk density
C	Chrom a
C¥	Hardness at infinite tim e
CA	Correspondence analysis
CATA	Check All That Apply
CD	Celiac disease
CE	Catechin equivalent
C_O	Hardness at time zero
C_t	Hardness at time t
CV	Cold viscosity 25 °C
Cxy	Circularity in XY plane
Cxz	Circularity in XZ plane
DPPH	2,2-difenil-1-picril-hidrazil
Esf	Sphericity
ETCxy	Extrusion transverse circularity
$F_{(t)}$	Weibull rejection function
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
FRAP	Ferric reducing antioxidant power
FV	Final viscosity
GAE	Gallic acid equivalents
GFP	Gluten free products
GRD	Gluten-related disorders
H	Hue angle
HCPC	Hierarchical Clustering on Principle Components
IBL	Instrumental half bowl life
k	Rate constant kinetics
L*	Lightness
LM	Hamm er mill

MBW	Incom e minimum Brazilian wage
MFA	Multiple factor analysis
MV	Minimum viscosity after heating
NCGS	Non-autoimmune and non-allergic disorders also called nonceliac gluten sensitivity
Num	Peak number
PCA	Principal component analysis
PCs	Principal componentes
PSD	Particle size distribution
PV	Peak viscosity at 95 °C
Pxy	XY plane
Pxz	Perimeter in XZ plane
R^2	Coefficient of determination
RVA	Rapid Visco Analyser
SBL	Sensorial bowl life
SEI	Sectional expansion index
t	Time
$t_{(½)}$	middle bowl-life
TCT	Total condensed tannins
TE	Trolox equivalent
TEAC	Trolox equivalent antioxidant capacity
TPC	Total phenolic compounds
WAI	Water absorption index
WGO	World Gastroenterology Organization
WSI	Water solubility index
X	Major axis
X_1,X_2,X_3	Sorghum BR305, Sorghum BRS373 and sugar respectively
Y	Middle axis
Z	Minor axis
α	Shape parameter in Weibull model
β	Scale parameter in Weibull model
σ	Scale parameter for rejection Weibull model
μ	Shape parameter for rejection Weibull model
μm	Micrometer

SUMMARY

INTRODUCTION

Sorghum grain is widely used in African countries as human food, this grain is the fifth cereal more produced after maize, wheat, rice, and barley. Sorghum is a low cost crop, drought resistant or low water dependency (convenient crop for water crisis and greenhouse effect) and also requires low fertilizer supply. It have the greater levels of antioxidants when compared to other cereals and carotenoids, as well as whole sorghum grain has high fiber content, proteins, and minerals hence it is considered an excellent functional food. In recent decades, sorghum has been studied to use to improve human nutrition in different areas of the world such us the USA, Japan, Europe, among others.

In Brazil, sorghum grain have an important place in animal nutrition, but in recent years it has been considered to be use in human diet because. As a result, a great number of works has been done to develop new sorghum based products that should attend consumer's expectations. Nevertheless, some sorghum products are not accepted as one would expect, particularly when tannin sorghum genotypes (which has high antioxidant capacity) is chosen to develop good accepted products. It is kwon that tannin and some flavonoids negatively influence the final product acceptability, in this context, some technologies could be used to improve sensory aspects allowing the use of additional benefits of their functional characteristics.

On the other hand extrusion cooking it's a versatile high temperature/shot time technology, with is able to reduce the negative sensorial effect of tannin, extrusion cooking of cereal allow extrudates which can be used as reedy to eat products i.e. breakfast products, infant foods, pregelatinized flours, pasta products, snacks, thin porridges, crisp bread, pet food, fish food, among others. Extrusion technology cooks and texturizes the melt through steam-induced expansion at the die, expansion define the final format and the structure and depends on temperature, moisture, solid rate, speed and screw configuration. The composition of raw material is critical in the extrudates production, thus, it is important to optimize the production process. There are few information about maximized the sensory acceptances in extruded products using sorghum with different composition in order to obtain ready to eat products with functional properties.

For the reasons addressed, this work aims to development of a product of high antioxidant capacity and sensory properties by using varied whole grain sorghum genotypes, the specific objectives were:

1. To understand why sorghum in not yet a common product used in human diet.
2. To choose whole grain sorghum genotypes with best antioxidant properties and acceptability using extrusion cooking.
3. To develop a breakfast cereal with best of both antioxidant capacity and sensory acceptability.

TESIS STRUCTURE

The thesis was development in four chapters, as follow:

Chapter	Title	Production until defense date
1	Sorghum, an alternative cereal for gluten-free products	Review article published in Revista chilena de nutrição on June 2018
2	Phenotypical and chemical characteristics of sorghum genotypes and their influences in physical, chemical properties and sensory acceptances after extrusion process	
3	Optimization of antioxidant capacity and sensory analisys of whole grain breakfast cereals using tannin and non tannin sorghum genotypes	
4	A new sensory bowl life methodology compared to instrumental bowl life	

CHAPTER I

Sorghum, an alternative cereal for gluten-free products

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Artículo de Revisión / Review Article

Sorghum, an alternative cereal for gluten-free product

Sorgo, un cereal alternativo para productos sin gluten

Davy Chávez[1,2], José Ascheri[3], Amanda Martins[1], Carlos Carvalho[3], Cristiany Bernardo[1], Aline Teles[4].

1. Universidade Federal Rural do Rio de Janeiro, Department of Food Science and Technology, RJ, Brazil.
2. Institute of Education, Science and Technology of Rio de Janeiro, Campus Valença, Department of Food Engineering, RJ, Brazil.
3. Embrapa Food Technology, RJ, Brazil.
4. Universidade Federal do Rio de Janeiro, Chemical Institute, RJ, Brazil.

Corresponding author: Davy Chávez.
Universidade Federal Rural do Rio de Janeiro,
Department of Food Science and Technology,
Rodovia Br 465, km 7, 23890-000, Seropédica, RJ, Brazil.
E-mail: davyhw76@gmail.com

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ABSTRACT

There is a growing demand for health foods, indicated by the number of searches including the terms "celiac disease" and "gluten free products". Most information is designed not only for celiac and gluten intolerant patients, but by others interested in obtaining additional health benefits from foods. Sorghum has been recently recognized as a cereal with functional properties, able to improve human health, but still of low direct human consumption. This review aims to illustrate the publication trends relating to sorghum for gluten free products and celiac disease. The scientific literature available in databases from the last twenty years was used. We perceived the need for further sensorial studies in order to understand the consumer expectations of gluten free products, considering the large varieties of colored sorghum grains that could be used to prepare different gluten free products.

Keywords: Meta-analysis; Antioxidant capacity; Sensorial analysis; Gluten free products.

RESUMEN

Existe una demanda creciente por alimentos saludables, indicado por el número de búsquedas sobre enfermedad celiaca y productos libres de gluten. La mayoría de la literatura atribuye esto, no solo a pacientes celiacos e intolerantes al gluten, pero también otras personas interesadas en obtener beneficios adicionales para la salud a partir de los alimentos que consumen. Además, el sorgo fue recientemente reconocido como un cereal con propiedades capaces de mejorar la salud humana, aunque aún con poco uso en la alimentación humana. Esta revisión tiene como objetivo probar las tendencias de publicaciones relacionadas con enfermedad celiaca y el potencial uso del sorgo para elaborar alimentos libres de gluten. Fue realizada una búsqueda sistemática en las bases de datos disponibles para los últimos 20 años. Los resultados permitieron percibir la necesidad de más trabajos relacionados con aspectos sensoriales para entender las expectativas de productos libres en gluten por parte de los consumidores, considerando la gran variedad de colores de granos de sorgo, esto podría ser usado para producir diferentes productos libres de gluten.

Palabras clave: Meta-análisis; Capacidad antioxidante; Análisis sensorial; Productos libres de gluten.

INTRODUCTION

In the beginning of the 21st century, food security became a public priority concern led by social, political and environmental problems at different scales[1]. The movement is founded on the idea of adequate nutrition, freedom from hunger and that the government has the obligation to provide food security for vulnerable groups, as part of international and regional conventions, agreements and protocols[2]. It is important that vulnerable groups may also be assisted by food safety protocols, as it refers to the reduction of the probability that certain food products may result in illness, injury, or even death.

Gluten-related disorders (GRDs) are triggered in certain individuals when products that contain gluten are consumed. Gluten is found in some cereals, such as wheat, barley or rye[4]. These individuals belong to a particular vulnerable group that is genetically and/or immunologically predisposed to suffer from GRD. This group can be subdivided into individuals suffering from allergies (wheat allergy), autoimmune diseases (celiac disease (CD) and diseases that are likely to be immune mediated (Non-celiac gluten sensitivity)[5,6].

Consumers with different GRDs require more options to eat. On the other hand, the number of gluten free products (GFP) is growing due to an increase of consumers with gluten intolerance and others that avoid products containing gluten and follow a GFP diet for lifestyle reasons. Nevertheless, there are not enough GFP options and quality and quantity of these products have not kept up with the rising demand[7,8]. Improvement of GFP is a challenge for the food industry and the number of studies on this topic has been on the rise.

Currently, non-conventional cereals such us sorghum and millet are not considered important plants for human nutrition in most countries of Europe, and North and South America. In those regions they are produced mainly for animal feed. In contrast, sorghum and millet are major food sources in many African and Asian countries, not only for human consumption, but because they have been considered as interesting crops due to their agronomical characteristics. They are drought resistant and have a low fertilizer requirement[10,11], which make them suitable to adapt in the new global warming scenario. In addition, sorghum is an interesting alternative for celiac patients and gluten intolerant consumers[1].

The process and consumption of sorghum, as a whole grain, fulfill functional and nutritional properties, due to its considerable dietary fiber (from 8,5 - 26,3 g/100 g), micronutrients (mg/100 g) such as K (363,0 - 338,2), Mg (151,0 - 165,0), Ca (11,5 - 12,4), P (375,0 - 384,5), and Mn (1,3 - 1,4), Zn (2,1 - 2,5), among others, and phytochemicals, such as tannin sorghum (10,0 - 68,0 mg/g), total phenolic (1,4 - 3,2 mg gallic acid/g), and others, which are present in the pericarp[1].

In developed countries, the consumption of sorghum, especially varieties with tannin, may promote intake of low calories associated with high antioxidant, dietary fiber content, with the consequent benefits for celiac disease, obesity and diabetes-related health problems[11,14,15]. Also, in developing countries, sorghum could represent an important income reduction mechanism in foreign grain import costs, hence the use of sorghum as a food for human consumption could help local economies additionally to their health benefits[1].

This work evaluates the current knowledge and ongoing information on CD and sorghum. It examines three important aspects: 1) CD; 2) Sorghum, as an alternative for human nutrition and health and 3) a metadata analysis regarding CD, sorghum and sensorial publications in order to understand the reasons why GFP are not sufficiently available worldwide.

Data collecting

FAOSTAT was used to collect the latest (2014) available crop information regarding sorghum production; the search was performed in June 2017. The Google trends search engine, accessed in June (2017), was used to find the terms "gluten free" and "Celiac disease" from 2004 to 2016. Also, the Scopus bibliographic database was consulted for the period 1997 to 2016, using the words: "sorghum", "celiac", "sensorial analysis", "food" and additional combinations. These terms were searched in the title, abstract and keywords.

Gluten-related disorders (GRD)

GRD can be classified into three groups: group 1, autoimmune disorders that includes CD, gluten ataxia (neurological manifestation of gluten intolerance) and dermatitis herpetiformis; group 2: allergies, e.g. wheat allergy (respiratory allergy, immediate food allergy, wheat-dependent exercise-induced anaphylaxis WDEIA, and urticaria; group 3: non-autoimmune and non-allergic disorders also called nonceliac gluten sensitivity (NCGS)[5,16]. Nonetheless, the difference the according to Hollon17, a gluten exposure can be resulted in increase in intestinal permeability.

The World Gastroenterology Organization[18] defines CD as a chronic, multiple-organ autoimmune disease that affects the small intestine in genetically predisposed children and adults. CD is a result of both intrinsic (genetic) and extrinsic variables (environmental)[19], other important factor to be consider is the immune dysregulation[4]. CD affects millions of people around the world and its prevalence is increasing[20]. CD affects 1 in 133 Americans, even though 1% of the U.S. population is thought to be afflicted with CD, with 97% of cases going undiagnosed[21]. On the other hand, CD is considered rare in Africa, China, Japan, Korea, Malaysia and immigrants from these countries, where consumption of wheat products is low[22].

Concerning the proteins responsible for GRD, prolamin is present in cereal grains, e.g., wheat (gluten), rye (secalin), and barley (hordein) that are known to bring about allergic response or detrimental autoimmune reaction in certain individuals[4,2].

Patients with GRD must avoid foods containing gluten (prolamin proteins coming from wheat, rye and barley) their entire lives[4]. Adults generally are conscious and able to prevent the consumption of GBP (e.g., baked goods and pasta) in daily life events, such as meetings and birthdays, particularly in Western diets. This situation becomes more difficult when travelling to locations where GFPs are not easily found, requiring persons to take their own food with them. But, the situation is much worse when children are affected, as they do not understand the reasons they must restrict their diets. The relationship with other kids and psychological status may be affected as they see their classmates and friends eating all foods containing gluten. Therefore, the entire family is affected with the restriction, which imposes changes in food habits[21].

From 2004, an increase in the number of searches using the term "CD" was observed up to 2012 when the number began to decline. The popularity of the term "GFP" in Google steadily increased until 2013 and remained stable to 2016 (Figure 1). The steep increase in CD articles in 2008 may be attributed to the increase of awareness influenced by international media events, mainly occurring in developed countries such as the USA, Italy and United Kingdom. When comparing the percentage of searches of both terms, CD is considerably lower (12 % of the number of searches in google in 2012) whereas GFP reached 89% in 2013 (Figure 1). Although searches for CD decreased, GFP kept increasing, which shows a clear concern and/or influence of health seeking issues of lifestyle change that may or may not be related to CD. According to Witczak[23], the market for GFPs is growing all over the world, as well as plant alternatives to make GFPs such as corn, potato, cassava, rice, sorghum, millets, buckwheat, amaranth, quinoa, legumes, flaxseed, chestnut, carob germ flour, lupin.

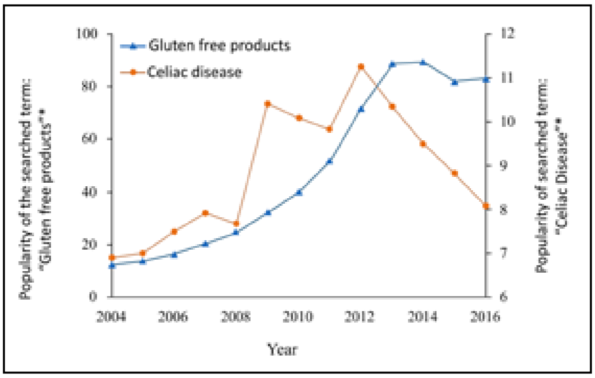

Figure 1. Trends in search related terms: "Gluten free products" and "Celiac disease" (www.google.com.trends), accessed in June, 2017. * Searched terms are relative to the total number of Google searches.

NCGS or simply, gluten sensitivity are reactions against gluten that involved neither allergic nor autoimmune mechanisms, nevertheless, the symptoms of NCGS could be similar to those of CD. The most prevalent NCGS disorders are abdominal pains, skin (eczema), headache, diarrhea, among others[5,6]. The diagnosis is difficult because there are no specific laboratory markers for NCGS. Thus, diagnosis alternative are conducted by exclusion, which begins by eliminating CD, then wheat allergy, following by a GFP. diet. As a result, the diagnosis could be made by an open challenge (monitored re-introduction of gluten containing foods)[5].

Wheat allergy is defined as an adverse immunologic reaction to wheat proteins which prevails in an average of 18% of food allergies The clinical manifestations are similar to other food allergies that present symptoms on the skin and in the respiratory track[16]. In wheat allergy, immunoglobulin E is cross-linked by repeated gluten peptides (eg, Ser-Gln-Gln-Gln-[Gln-]Pro-Pro-Phe). Additionally, the release of immune mediators such as histamine from basophils and mast cells are induced by non-gluten proteins. On the other hand, CD is an autoimmune disorder, which is diagnosed based on serologic markers such as serum antibodies against tissue transglutaminase-2, followed by intestinal biopsy[5].

Sorghum

Sorghum is a low cost cereal crop characterized by its efficient use of water, resistance to drought and poor soil requirement fertility, as it originated from arid regions of Africa, although there are reports mentioning that it is also native to India[15]. Currently, it can be found in other arid zones of Australia, Central, South America, and North America[25,26]. Sorghum is the major source of carbohydrates, energy and proteins in African and Asian countries. These regions produce different sorghum food types[27], including breads, tchapalo or sorghum beer, popped sorghum, and porridge, among others[28]. In most industrialized countries such as the USA, Europe and other developing countries like Mexico, Brazil, Argentina, among others, sorghum is mainly used for feed[8,29].

Since 1977, sorghum yield has been growing more than any other crop in drought and semiarid areas around the world, as reported by Bookwalter, Warner[26]. In addition, as mentioned by de Mesa-Stonestreet[21], "sorghum utilization helps in food security issues because it is a drought resistant crop that easily withstands harsh cultivating conditions in impoverished regions of Asia and Africa". This sentence is a clear call for awareness that food security is an urgent topic of discussion with respect to global warming.

Sorghum is currently the fifth most produced cereal, following maize, wheat, rice, and barley. Sorghum belongs to the Poaceae family, like wheat, rye, barley, and oat (Figure 2), but from a different subfamily, Panicoideae. Wheat, rye and barley are classified in the same tribe (triticeae), whereas oat and sorghum are divided in avenae and andropogoneae, respectively.

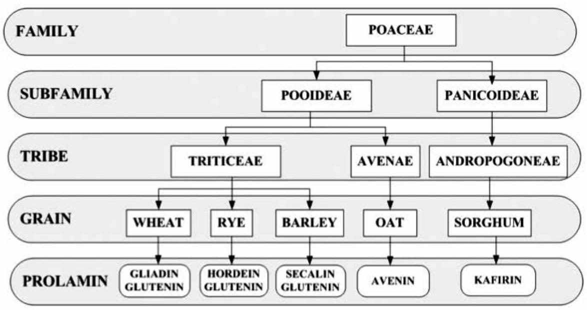

Figure 2. Taxonomy of Poaceae family and their typical proteins, adapted from: Kupfer and Jabri4; de Mesa-Stonestreet, Alavi[21]; Vallabhaneni, Bradbury[40].

According to Ratnavathi and Patil[29], sorghum is known for its nutritional quality. Nevertheless, the global direct consumption is low and it is considered a marginal crop when compared rice, wheat and maize. Concerning its nutritional value, in a study of 100 sorghum genotypes, cultivated under controlled water stress condition, Queiroz[30], reported minimum and maximum values (g/100g) of the following components: carbohydrates (54,6 - 77,2), proteins (7,8 - 19,0), dietary fiber (8,5 - 26,3), lipids (1,6 - 5,0) and ash (0,9 - 2,8). Sorghum prolamins are named kafirins, which are considered safe for celiac patients[12].

The consumption of sorghum in countries with obesity and diabetes problems may contribute to reduced digestibility, which in turn, it is an attractive option for developing sorghum based low calorie health foods[32,33]. The major phenolic compounds present in sorghum are ferulic acid (120,5 - 652,1μg/g)[35,12], p-coumaric acid (41,9-68,1 μg/g)[35,12], vanillic acid (30,1 - 61,4 μg/g)[12], condensed tannins (proanthocyanidins), 3-deoxyanthocyanins, 4-coumaric acid, 4-hydroxybenzoic acid, caffeic acid, caffeoylglycerol and coumaroylglycerol[12,34,35]. The secondary metabolics present in sorghum grain has the highest level of antioxidants, that can vary from 2,5 to 17,5 μM trolox/g (ABTS), from 12,8 to 27,7 μM trolox/g (DPPH) and 1,0 to 28,4 μM trolox/g (FRAP), when compared to other cereals[12,35,3].

Sorghum is a good source of vitamins, particularly E and B complex, and minerals[28]. Also, most sorghum genotypes are rich in bioactive compounds like phenolic compounds[12,37], exact amount varies depending on the sorghum genotype. Other bio-actives present in sorghum grains are flavonoids (45,9 - 58,8 μg/100 g)[35], condensed tannins, (19,2 - 67,4 μg/100 g)[35,37,38,39], vitamin E (tocopherols/tocotrienols between 1,5 and 117,9 μg/100g)[38], carotenoids (Lutein from 0,4 to 63,4 μg/100 g and Zeaxanthin from 1,4 to 58,8 μg/100 g)[40], anthocyanins (3-Deoxyanthocyanin, from traces to 45 μg/100 g)[32] favoring an increased antioxidant capacity, that has been studied by many authors[10,12,26,32,37].

Consequently, sorghum is considered a functional food[12,14,41]. It has been recently reported that sorghum presents anticarcinogenic and antimutagenic properties[28,32,38], as well as reducing cardiovascular disease, diabetes and obesity[32]. In addition, the health use of sorghum proteins for CD patients and different levels of gluten intolerant consumers has been extensively reported[8,12,21,26,28,32].

Sorghum-made food product

Most products produced with sorghum are found in India and some African countries[25,39]. In West Africa the consumption of sorghum beverages (alcoholic and non-alcoholic) is common. Examples include: Dolo (Burkina Faso), Burukutu (Ghana), Pito (Ghana), Gowé (Benin) and Ran-noodo[42]. The combination of soghum and maize is called Kunu and is found mainly in northern Nigéria[43]. In a review by Ratnavathi and Patil[29], the authors compiled a list of foods made from sorghum and its mixture with other cereals. Some of them are described below:

Tortillas are a traditional Mexican food, conventionally based on calcium oxide treated maize, also called nixtamalization, this same process is also carried out with sorghum to produce very fine circles that is baked[44].

Roti or bhakri is made with a fine whole sorghum flour that is baked on rolling[45].

Injera is a bread made from fermented dough for about 48 h and baked for 2-3 min[46].

Kanji or ambali is a porridge prepared from whole sorghum flour of low consistency that is consumed in the southern parts of India, Africa and Central America[47].

Tô is made from decorticated soghum grain that is milled into a flour, that is cooked for about one hour in water (1:4) with small amount of tamarind or lemon juices and allowed to cool (1 h)[48].

Annam is made of dehulled boiled sorghum grains in water (1:3) until grain softness is achieved, and then the excess of water is drained off[45].

Upma is a breakfast food or snack prepared with wheat semolina and polished milled sorghum. It is made with a little oil in a sauce pan and seasoned with grains like chickpeas along with mustard and cumin seeds[47].

Sankati is a type of thick porridge made from grits or flour of milled sorghum grain that is boiled for 10 min with water (1:3). Then, fine flour is added by stirring for about 3 min and 10 cm diameter balls are made, eaten fresh or stored overnight[43].

Dosa and Idli are fermented breakfast foods. Idli is made in molds and steam cooked, while Dosa is a thin, oily pan cake[47].

Muruku, chakkalu and namak (Snack foods) are made by frying blended sorghum flour. These products could compete with snacks made from corn, rice and wheat[29].

Ugali is main made of brown sorghum, but also with white grains that is served as a stiff porridge[49].

Ogi is made from dehulled or whole milled sorghum and is cooked with water, vegetables, meat and other ingredients to produce a type of soup[50].

Kisra is prepared by mixing 60% whole sorghum flour and 40% water and then fermented for 12-24 h until a sour taste is obtained[51].

Couscous is a coarse granulated sorghum flour (whole or dehulled) with water it is turned into agglomerated particles that are consumed with milk and other sauces[49].

The partial or total substitution of wheat with local flours originated a basted bakery product like bread (whole sorghum), plum cake and biscuits, noodles and pasta. Popping sorghum is a common product too. On the other hand, the extrusion cooking technology has opened a wide variety of products with high commercial values based on the good extrusion qualities of sorghum (in some cases it presents similar properties of extruded corn and rice products)[29].

Metadata analysis

The number of scientific publications regarding the term "celiac" was higher (Figure 3a) than any other, totalizing 24.239

(from 1997 to 2014). When the term "celiac and food" (Figure 3a) was used, the number of publications drastically reduced from thousands to hundreds per year totaling 2.382, which represented about 10% of the search term "celiac". Although the number of publications was low when "food" term was considered, there is a steady increase in publications that it is believed traditional and nontraditional foods have been investigated and/or develope.

When compared to "celiac", the term "sorghum" appeared in 13.594 research articles (Figure 3b), whereas "sorghum" and "food" terms totaled 2.210 published works, indicating that sorghum for food uses are comparably low and still deserves attention. By combining "sorghum" and "celiac" terms, only 54 articles were found (Figure 3d). The first articles that considered these terms appeared in 2004 and in 2016 the just three mentioned the term.

In order to develop a food product, it is very important to have it evaluated by sensory analyses. By following a market rule, "sensorial" and "food" terms were also searched for in scientific publications. As expected, a considerable number of articles was found (1,608) from 1997 to 2016 and expressive growth over the years (Figure 3c).

When "sorghum" and "sensorial food" terms were searched, only 200 articles were found (Figure 3c). It is worth noting that only 17 articles were found when "celiac" and "sensorial" were searched together (Figure 3d), indicating a strong need to develop new sorghum food products for CD patients with good quality and acceptance[23]. Sensorial studies and characterization are the key to evaluate and develop products[52].

The USA, India, Brazil and China are the countries with almost 55% of published articles on sorghum (Figure 4a). The countries with research based on developing food for humans using sorghum are USA, India, Nigeria, South Africa, China and Brazil with almost 45% of articles (Figure 4b). The USA and European countries appear to be mainly concerned with CD (Figure 4c), as opposed to African and countries from the Indian sub-continent, where CD is believed to be scarce18. Data analysis also revealed three countries where sensorial analysis in food is emphasized (Figure 4d): Spain (13,7%), Brazil (12,5 %) and Italy (12,1%).

A list of published data from the last few years (2015-2017) on the use of sorghum food applications is displayed in Table 1. It is worth noting that only recently, a growing concern on producing acceptable foods using sorghum that combine good sensorial appeal and health benefits is observed. The list shows a scarce number of technical publications that evaluate sorghum products using sensorial techniques.

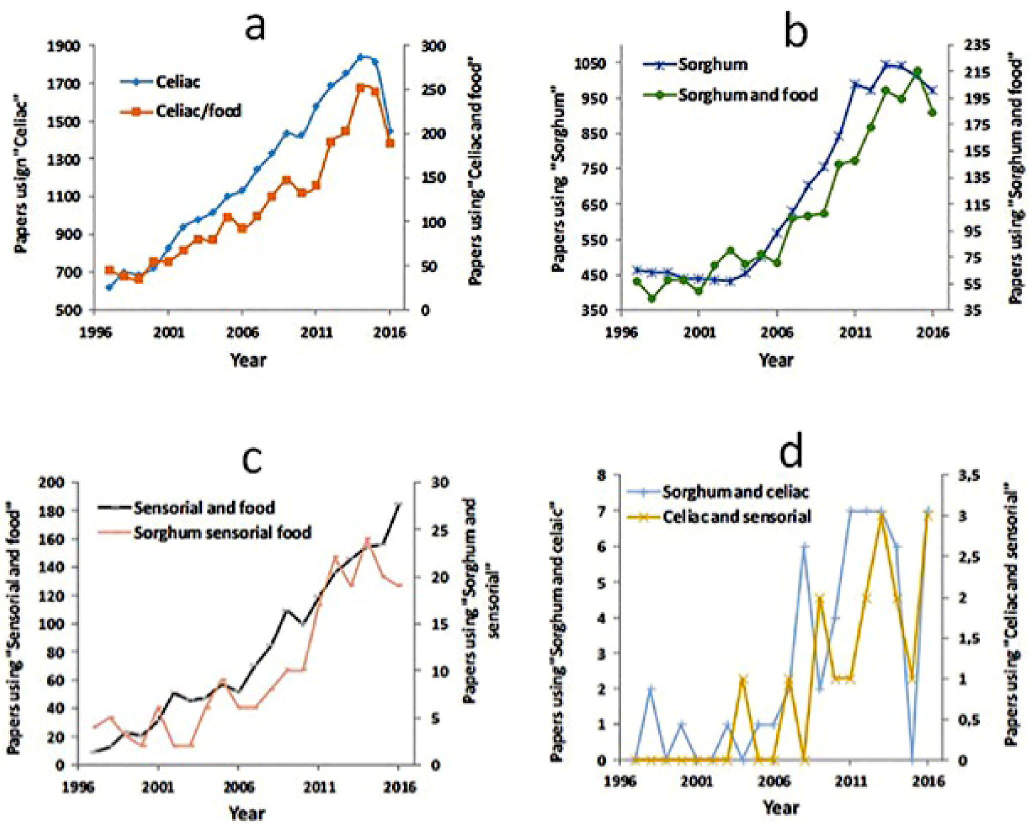

Figure 3. Number of scientific articles from 1997 to 2016 using Scopus metadata. This search was carried out in June, 2017.

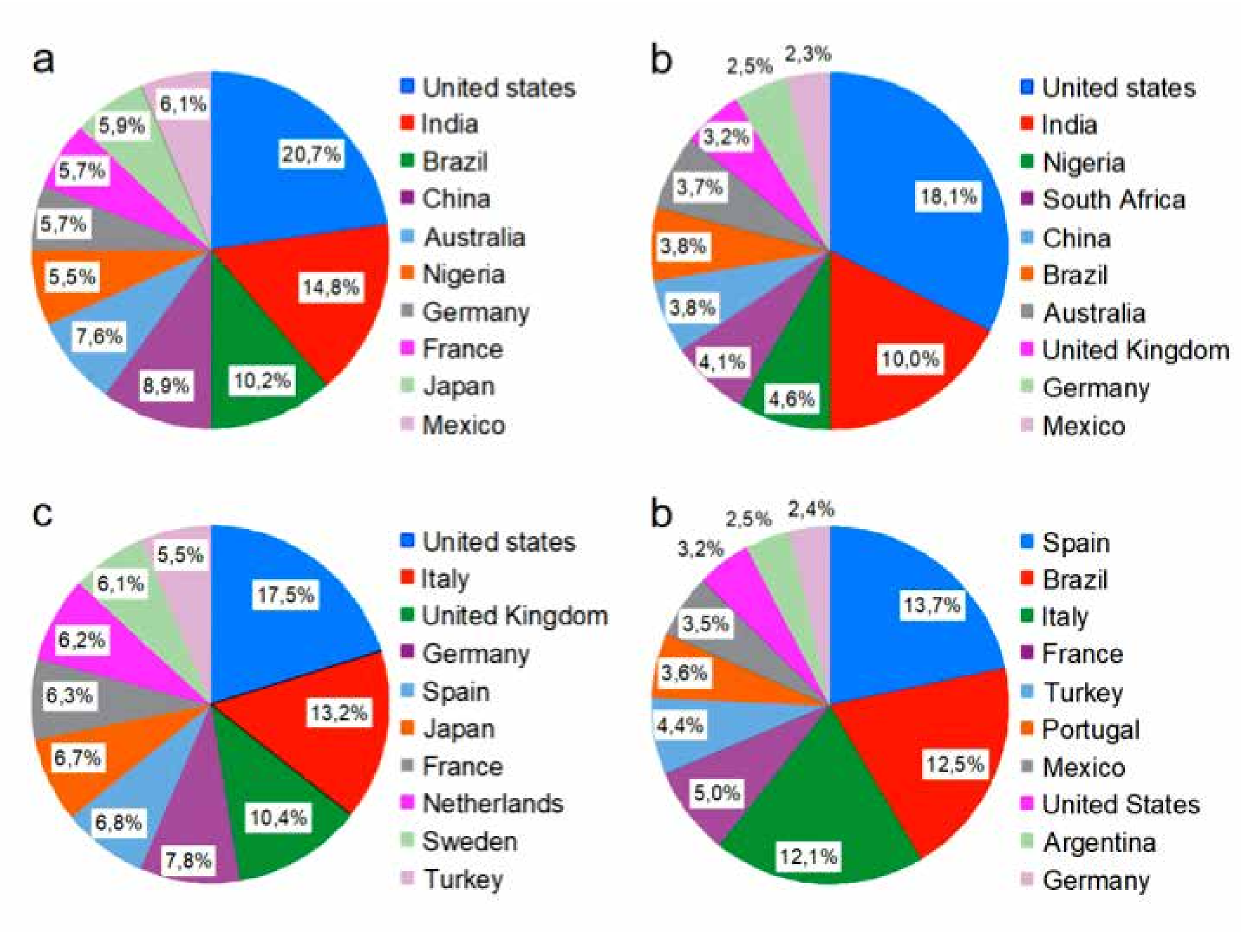

Figure 4. Top ten countries in publications regarding the searched terms: a) "sorghum", b) "sorghum and food", c) "celiac" and d) "sensorial and food" by employing Scopus metadata. This search was carried out in June, 2017.

Table 1.
An overview of recent (last two years) publications using sorghum as directly consumed food product.

Title	Sensorial study	Reference
Mashing with unmalted sorghum using a novel low temperature enzyme system: Impacts of sorghum grain composition and microstructure	No	Holmes et al.[53]
Sorghum and roasted coffee blends as a novel extruded product: Bioactive compounds and antioxidant capacity	No	Chávez et al.[12]
Comparing sorghum and wheat whole grain breakfast cereals: Sensorial acceptance and bioactive compound content	Yes	Anunciação et al.[38]
Peroxidases from root exudates of *Medicago sativa* and *Sorghum bicolor:* Catalytic properties and involvement in PAH degradation	No	Dubrovskaya et al.[54]
Resistant starch content among several sorghum (*Sorghum bicolor*) genotypes and the effect of heat treatment on resistant starch retention in two genotypes	No	Teixeira et al.[15]
Physicochemical properties of sorghum and technological aptitude for popping. Nutritional changes after popping	No	Llopart and Drago[13]
Nutritional composition of sorghum [*Sorghum bicolor* (L.) Moench] genotypes cultivated without and with water stress	No	Queiroz et al.[31]
Composition, in vitro digestibility, and sensory evaluation of extruded whole grain sorghum breakfast cereals	Yes	Mkandawire et al.[33]
Proline over-accumulation alleviates salt stress and protects photosynthetic and antioxidant enzyme activities in transgenic sorghum [*Sorghum bicolor* (L.) Moench]	No	Reddy et al.[55]
Tocochromanols and carotenoids in sorghum (*Sorghum bicolor* L.): Diversity and stability to the heat treatment	No	Cardoso et al.[56]
Dual modification of native white sorghum (*Sorghum bicolor*) starch via acid hydrolysis and succinylation	No	Mehboob et al.[57]
Process optimization for a ready-to-serve breakfast smoothie from a composite milk–sorghum base	Yes	Rani et al.[58]
Sorghum-cowpea composite porridge as a functional food, part II: Antioxidant properties as affected by simulated in vitro gastrointestinal digestion	No	Apea-Bah et al.[59]
Effect of heat treatment of sorghum flour on the functional properties of gluten-free bread and cake	Yes	Marston et al.[60]
Utilization of sorghum, rice, corn flours with potato starch for the preparation of gluten-free pasta	Yes	Ferreira et al.[61]

CONCLUSIONS

The consumption of GFPs has experienced an exponential increase in the last few years, particularly from 2006. This outstanding increase was not only caused by the rise in incidence of CD and gluten intolerance, but also due to the consumer´s concern for eating healthy foods–absent of gluten, but with beneficial increments of dietary fiber, bioactive compounds and antioxidant capacity. In this review, we have shown that sorghum grain has important functional food characteristics. Thus, it can be considered a health food alternative for the population, particularly, for persons with CD and those with lower levels of gluten intolerance. However, it was also observed and demonstrated here, based on the online search engines, that there are limited number of GFP. Also, more sensorial studies are the key to meet the challenge of developing palatable GFP based in sorghum.

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Phenotypically and chemical characteristics of sorghum genotypes and their influences on the physicochemical and sensory properties of sorghum extrudates

Resumo

O sorgo é consumido em países da África e da Ásia, sendo uma cultura tolerante à seca e ao calor. O grão de sorgo é também considerado um alimento saudável por conter significativo teor de antioxidantes naturais, fibra alimentar, sendo o seu consumo indicado para celíacos e pessoas intolerantes ao glúten. Hoje em dia em alguns países o uso de sorgo devido ao alto teor de compostos bioativos e seus benefícios para a saúde, apesar de certas cultivares de sorgo (especialmente cultivares com maiores valores de compostos bioativos) possuírem algumas características sensoriais indesejáveis. Neste trabalho foram utilizados seis genótipos de sorgo (pericarpo marrom BR305 e SC319; pericarpo vermelho BRS373 e BRS330; pericarpo branco BRS501 e CMSS005). Com o objetivo de selecionar genótipos que poderiam ser apropriados para o desenvolvimento de cereais matinais, os grãos de sorgo foram caracterizados por análises físico-químicas, capacidade antioxidante e textura (dureza). Os extrudados foram caracterizados quanto ao índice de expansão radial, viscosidade da pasta e textura (crispness). Com relação aos aspectos sensoriais dos extrudados de sorgo, foi adotada a aceitação do consumidor numa escala de 1 a 9, o teste Check All That Apply ou questionário CATA e aintensão de comprarcom escala de 5 pontos. Os genótipos de sorgo BR305 e SC319 apresentaram os maiores valores de fibra alimentar (11,38% e 14,57%). Em geral, a dureza dos grãos tiveram correlação de Pearson inversa com umidade (r = -0,850 p<0,05) e diretamentacom o teor de proteína e cinzas, com valores de r de 0,968 e 0,930 (p <0,05), respectivamente. Com relação aos extrusados, o sorgo branco BRS501 e CMSS005 (valores L * de 43,2 e 60,3, respectivamente) apresentaram os maiores valores de expansão radial (4,12 e 6,6), foi observada correlação negativa da expansão radial com os compostos fenólicos totais, DPPH e ABTS (-0,904, -0,875 e -0,890, respectivamente). Os genótipos BR305 e SC319 apresentaram os maiores valores de capacidade antioxidante, mas apresentaram valores de aceitabilidade mas baixos (4,3 e 4,5) e essas amostras também foram relacionadas a sabores amargos e ruins pelo questionário CATA. A partir deste trabalho, foi possível observar que os extrudados produzidos com genótipos de sorgo com maiores propriedades antioxidantes apresentaram baixa aceitabilidade. Portanto, dois genótipos diferentes de sorgo (BR305 e BRS373 com e sem tanino respetivamente) foram combinados de forma a se obter um produto final com boa capacidade antioxidante e aceitabilidade.

Palavras-chave: Sorgo com tanino, aceitação do consumidor, CATA, capacidade antioxidante, agrupamento hierárquico a partir dos componentes principais.

Abstract

Sorghum is consumed in African and Asian countries. It is drought resistant and considered a healthy food, including for celiacs and gluten intolerant patients. Nowadays it has been seen the use of sorghum to prepare food products due the high bioactive compounds content that leads to health benefits. Nevertheless certain sorghum cultivars (especially cultivar with high values of bioactive compounds) has some undesirable sensory characteristics. In this work, six sorghum genotypes (BR305 and SC319 brown pericarp; BRS373 and BRS330 red pericarp; BRS501 and CMSS005 white pericarp) were used to appropriate select genotypes that could be used to breakfast cereals development, the sorghum grains were characterized by physic-chemical, antioxidant capacity and texture analyses (hardness). The extrudates were characterized concerning expansion indices, paste viscosity and texture (crispness). Regarding the sensory aspects of sorghum extrudates, the sensory evaluation techniques: consumer acceptance from 1 to 9 scale, The Check All That Apply (CATA) questions and Buy intention test with 5 point scale were applied. Sorghum genotype BR305 and SC319 presented the highest values of dietary fiber (11.38% and 14.57%). In general, grain hardness was Pearson inversed correlation with moisture ($r=-0.850$ and $p<0.05$) and direct correlated to protein and ash content, with r values of 0.968 and 0.930 ($p<0.05$), respectively. Concerning the extrudates, white sorghum BRS501 and CMSS005 (L* values of 43.2 and 60.3 respectively) presented the highest values of sectional expansion index (4.12 and 6.6). It was observed negative correlation of SEI with total phenolic compounds (TPC), DPPH and ABTS (-0,904, -0.875 and -0.890, respectively). BR305 and SC319 genotypes showed the highest values of antioxidant capacity, but low values of consumer acceptance (4.3 and 4.5, meaning dislike slightly and neither like nor dislike, respectively) and these samples were also related to bitter and bad tastes by CATA questions. From this work, was possible to observe that those extrudates produced with sorghum genotypes of high antioxidant properties presented low acceptability. Therefore, it would be advisable to combine two different sorghum genotypes (BR305 tannin sorghum and BRS373 non-tannin sorghum), in order to have a final product with good antioxidant capacity and acceptability.

Keywords: Tannin sorghum, consumer acceptance, CATA, antioxidant capacity, hierarchical clustering principal components.

INTRODUCTION

Whole sorghum grain is a good source of minerals, fibers, vitamin E, carotenoids and it is considered a food with functional properties due to its bioactive compounds such as antioxidant capacity. It has the highest level of antioxidant capacity among traditional cereals (RAGAEE et al., 2006; ANUNCIAÇÃO et al., 2017; CHÁVEZ et al., 2017), high content of phenolic known to have anti-inflammatory activities, to prevent anti-cancer, diabetes, hypertension, atherogenesis and coronary heart diseases, among others (AWIKA; ROONEY, 2004; SALAWU et al., 2014). Sorghum also has resistant starch (RAGAEE et al., 2006) and high amount of dietary fibers (QUEIROZ et al., 2018). It is a gluten free grain, thus it can be consumed by everyone without triggering any gluten-related disorders (YOUSIF et al., 2012). In addition, sorghum has interesting agronomical qualities such as drought resistance, low water dependency (convenient crop for water crisis and greenhouse effect) and also requires low fertilizer supply (YOUSIF et al., 2012; N'DRI et al., 2013; ROSE et al., 2014; QUEIROZ et al., 2015). Sorghum is also abundant in more than 20 minerals, especially in phosphorus, potassium, iron and zinc (RANI et al., 2016).

In some countries (Australia, United States and Brazil), whole sorghum grain is principally used for animal feeding. On the other hand, in Africa, Asia and other semi-arid regions, this grain is used mainly for human consumption. Nowadays, the use of sorghum for human consumption in Western countries has increased due to its functional potential (Chávez et al., 2018). Therefore, sorghum is an excellent option to develop new healthy foods. There are considerable number of sorghum genotypes with variable pericarp colors and interesting phytochemicals to human nutrition. This variation could include variation in nutrient composition, the variation depend on different factors such as genetic background, soils, weather, seed-filling period, thus, the selection for high nutritional content should be preceded by analyses for genotypes (QUEIROZ et al., 2015). The previous authors reported a study in 2015, in which was determinate the composition of 100 sorghum genotypes in two conditions with and without water stress, but the work not abording the effect of the sorghum genotype in their technological responses. However, most studies do not consider more than one or few sorghum genotypes and they generally focused on few properties. The aim of this work was to compare six sorghum genotypes considering their effect of selected grain characteristics on the extrusion and sensory analyses of the final extruded products.

MATERIALS AND METHODS

PLANT MATERIALS

Six sorghum genotypes with different phenotypic characteristics were provided by Embrapa Milho e Sorgo (Brazilian Agricultural Research Corporation). The experimental field is located at 19° 28´ south latitude and 44° 15´08´´ and longitude W Grw, and 32 m of altitude. The sorghum genotypes were: BR305 (brown); BR501 (white), SC319 (brown); CMSS005 (white), BRS330 (red) and BRS373 (red). The sorghum was planted in the experimental field in May 2014, and the harvesting took place in May 2015. The kernels were cleaned and stored at 8 ± 2 °C until the analyses.

Chemical composition

Whole grain composition analyses (moisture, ash, lipid content, and total nitrogen content) were performed (duplicates) following the methods described by AOAC (2010). A conversion factor of 5.75 was used to calculate the protein content from the total nitrogen, and the moisture was calculated by the differences from the other components.

Antioxidant determinations of raw sorghum

The samples were extracted twice to obtain the maximum hydrophilic and hydrophobic compounds. One gram of the milling sample was mixture with 5 mL of methanol (50%), into a 15 mL test tube, homogenized in a vortex (Genie 2 Scientific Industries, Bohemia, NY, USA), resting by 30 min, posteriorly was centrifuged at 9000 *g* for 15 min, filtered through a rapid past paper. The second extraction was done using the solid residue by adding 5 mL of acetone (70%) and following the same steps. The supernatant were joined in other 15 test tube and the volume was complete until 10 mL ultrapure water.

DPPH, ABTS. The antioxidant capacity were determined using synthetic free radicals (DPPH and ABTS) methods described by Re et al. (1999) and Brand-Williams et al. (1995). The absorbance of the reaction after 30 min was red at 734 nm and 515 nm respectively in a spectrophotometer UV-1800 (Shimadzu Corporation, Kyoto, Japan). It was used Trolox curves (for each assay ABTS and DPPH) as standards. Three replicates were made and the results were expressed in µmol Trolox equivalent/gram of sample (µmol TE/g) antioxidant capacity (TEAC) and were calculated dividing the gradient of the inhibition percentage vs. sample concentration by the gradient of the plot of the inhibition percentage (Equation 1) vs. Trolox concentration for each assay (RE et al., 1999; CHÁVEZ et al., 2017).

$$\% \, inibition_i = [(Abs_{rad} - Abs_s) * 100/Abs_{rad}] \quad 1$$

Where: i is the radical ABTS or DPPH; Abs_{rad} is the absorbance of the radical, and Abss is the absorbance of the sample or trolox.

Total phenolic compounds (TPC)

TPC was quantified according to the colorimetric method described by the Folin–Ciocalteau (LUDWIG et al., 2012). The extract (20 µL) was diluted with 1580 µL water and 100 µL of Folin-Ciocalteu reagent, resting for 2 min, the was added 300 µL of 7.5% (w/v) sodium carbonate solution, mixed and kept in darkness at 50 °C for 15 min. It was used Gallic acid as a standard (concentration ranged from 0.03 to 1.5 mg/mL). The absorbance was read at 760 nm using a spectrophotometer UV-1800 (Shimadzu Corporation, Kyoto, Japan). TPC were expressed as mg of Gallic acid equivalents (mg GAE)/g.

Total condensed tannins (TCT)

TCT were quantified using vanillin acidified method, described by Broadhurst e Jones (1978), vanillin–methanol 4% (w/v) was added to the extracts, mixture by vortex and rested for 20 min in the darkness and at room temperature. The absorbance was measured at 500 nm. Results were expressed as mg catechin equivalent (mg CE/g) by using a calibration curve of catechin.

Weight and hardness grain measurement

Grains (n = 130) were random selected for weight and texture measurement. The hardness was measurement on a Texture Analyser TA-XT Plus equipment (STable Micro Systems, Surrey, England) running by Exponent software 6.1.11.0 (STable Micro Systems, Surrey, England). The instrument was equipped with a 30 kg load cell, 15 mm stainless steel cylinder probe. The test was adjusted in mode “measure force” in with probe distance of 10 mm, pre-test speed of 10 mm/s, test speed of 1 mm/s and post-test speed of 10 mm/s. Compression occurred until reach the 50% of the sample high (stain), data was take after the contact of the probe with the sample and reach a trigger force of 0.5 N. The Hardness was defined as the peak force of the first compression required to make a rupture in the sample (OLIVEIRA et al., 2017).

Shape image characteristics of the entered grain

Grains (n = 100) was put carefully in a surface (contract color background) arranged in rows and columns (a ruler was as a knowing scale). The measurements was performed using image analysis with ImageJ free software (http://imagej.nih.gov/ij/). There were taken two pictures (Figure 1), a) one was perpendicularly to the orthogonal XY plane (transverse section), X represent the major axe of the grain and Y middle bigger axe, in similar way, b) the second picture was taken perpendicularly to the orthogonal XZ plane (longitudinal section), were, Z was the little axe. The pictures were taken by using a digital camera (Nikon, D7200 N1406, Nikon corporation, Thailand, equipped with an optical macro Sigma 105 mm 1:2.8 DG MACRO HSM). Camera settings are describing in Table 1.

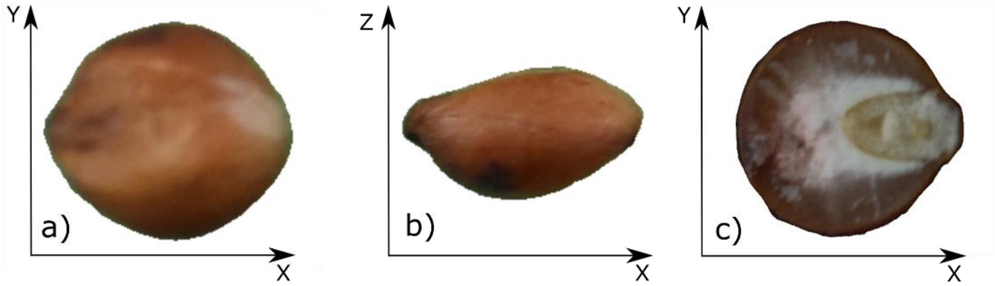


Figure 1. a) Transverse picture for a whole grain (XY plane), b) longitudinal picture for a whole grain (XZ plane) and c) Transverse picture for a half sorghum grain (XY plane).

ImageJ software (http://imagej.nih.gov/ij/) was used to obtained the following measurements: a) the XY plane Area (Axy), perimeter in XY plane (Pxy), major axis (X), middle axis (Y), Circularity in XY plane (Cxy), and Area in XZ plane (Axz), perimeter in XZ plane (Pxz), minor axis (Z), Circularity in XZ plane (Cxz). Additionally, the sphericity was calculated with the relation on the three axis (Equation 2).

$$Esf = \left(\left(X.Y.Z \right)^{1/3} \right) / X \qquad 2$$

Where: Esf, is the sphericity and X, Y and Z are the axis of the sorghum grain and X is the major axis.

Table 1. Camera configuration for taking pictures of the grain for morphological measurements

Characteristics	Entire grain	half grain	Extruded
Focal distance	29.4 cm	29.4 cm	10 cm
Digital Zoom	1	1	1
Flash	Off	Off	Off
Iso velocity	160-IOS	200- OSI	400- OSI
Operation mode	Manual	Manual	Manual
Aperture Av	f/9	f/13	f/13
Exposure Tv	1/100 s	1/60 s	1/15 s
Quality	JPG	JPG	JPG
Macro	On	On	On

Instrumental color measurement

Color parameters was collected using a colorimeter Color Quest XE (Hunterlab, Reston, USA) adjusted in specular mode, with an opening diameter of 0.375 mm. The collected color parameters for reflectance of CIELAB were: L, a* and b*, additionally Chroma (C) indicates color purity or saturation (high values are more vivid) and hue angle were calculated using equations 3 and 4.

$$C=\sqrt{a*^2+b*^2} \quad (3)$$

$$H=\arctan\left(b*/a*\right) \quad (4)$$

Were: C: chroma, H: hue angle, brightness (L), redness (+a*), greenness (-a*), yellowness (+b*), and blueness (-b*).

Inside characteristics of the sorghum grains

The inside morphological characteristics was measurement using pictures of half grains (n = 10), cutting in transverse cross section (XY plane) (Figure 1c), each grain was put with and know scale and take a picture perpendicularly with a digital camera (Nikon, D7200 N1406, Nikon corporation, Thailand) equipped with an optical macro Sigma 105 mm 1:2.8 DG MACRO HSM). The camera configurations showing in Table 1.

Particle size distribution (PSD) of sorghum hole flour

The sorghum was cleaned (when needed) and drying in a fan oven at 60 °C for 24 h, cooled and milling in a hammer mill (LM) model 3100 (Perten Instruments AB, Huddinge, Sweden) fitted with a 1.0 mm sieve aperture. PSD was determined using a rotator-tapping sieve shaker Rotachoc (Chopin Instruments, Villenueve-LaGarenne, France), using 100 g of the hole flour and shaker for 10 min, according to the method described by Vargas-Solórzano et al. (2014), with some modification in sieve size to obtain a normal particle distribution (mesh/sieve opening in µm): 30 (590 µm), 40 (420 µm), 60 (350 µm), 70 (210 µm), 100 (149 µm), 140 (105 µm), 230 (62 µm) and the pan (particles < 63 µm)). The results were expressed at PSD (ESCALANTE-ABURTO et al., 2013), using the equation 5.

$$\text{PSD}(\%)=(\text{reteined flour in each sieve } (\text{g})/\text{initial flour sample } (\text{g}))\text{ x }100 \tag{5}$$

Where, PSD_i (%) particle size distribution, n is the number of sieves (8 including the pan).

Extrusion conditions

Sorghum flours moisture was standardized at 11.00 g/100g and rest for 24 h at 8 °C before the extrusion to equilibrate the water distribution, the water standardized was performed by added the necessary water to sorghum flour to achieve 11% water content (wet basis). The extrusion was performed using a corotating, intermeshing twin-screw extruder with screw diameter of 25 mm extruder Evolum HT25 (Clextral Inc., Firminy, France), length: diameter ratio of 40:1 and ten temperature zones (from feeding to die): 25, 40, 60, 90, 110, 110 110, 120, 120 and 120 °C, running at screw speed of 500 rpm. The feed rate was kept constant at 10 kg/h, the die had four holes of 3.88 mm, following by a cutting head device of four blades at a speed of 900 rpm. The product was collected after the process stabilization, then, drying in a fan oven at 60 °C for 4 h, cooled and stored at 8 °C for further analysis.

Sectional expansion index (SEI) by using image analyses

The SEI was calculated using the equation 7, proposed by Alvarez-Martinez et al. (1988). Nevertheless, some modifications were made to obtain measurements to SEI calculation, due in some cases the extrude had no defined format (e.g. horseshoe format) with insufficient space to diameter measure using a vernier caliper, as usually reported by different authors (NAYAK et al., 2011; DO NASCIMENTO et al., 2012; NASCIMENTO et al., 2017; OLIVEIRA et al., 2017). As in shape sorghum analysis, the measurements was carried out by a free software ImageJ available in http://imagej.nih.gov/ij/. It was used tem extrude pictures. The picture were taken with a digital camera (Nikon, D7200 N1406, Nikon corporation, Thailand, equipped with an optical macro Sigma 105 mm 1:2.8 DG MACRO HSM), camera configuration is presenting in Table 1. On the other hand, when use a picture with a knowing reference scale to take digital measurements by a computational program the existences of, thus, the measurement numbers could be many more than those obtained by a Vernier. In this study was collected the diameter of ten point by using equation 6:

$$SEI = \left(D / D_o \right)^2 \qquad 6$$

Where, D is the medium extrudate diameter (mm) after cooling and D_o is the die diameter (mm).

Instrumental texture extrudates characteristics

The extrudates were drying (60 °C x 4 h) before the texture analyses. The texture was measurement (n=30) on a Texture Analyser TA-XT Plus (STable Micro Systems, Surrey, England) running Exponent software 6.1.11.0 (Stable Micro Systems, Surrey, England). The equipment was fitted with 30 kg load cell, 50 mm diameter cylinder aluminum probe (1963.50 mm^2 contact area) and a back extrusion rig of 50 mm diameter and 75 mm high. Inside the back extrusion rig 7.8 to 9.2 g of the sample was gently placed until reaching around 25% of the rig top. Hardness and crispness was measured using the same configurations for measuring grain hardness. Crispness is defined as a total number of measured force peaks (BOUVIER, BONNEVILLE ; GOULLIEUX, 1997).

Pasting characteristic of the extruded flours

The extrudates was ground using a LM, then was sieved and the retained fraction between 212 and 106 μm was used in past characterization analyses to determinate the degree of starch modification after the extrusion process. Water absorption index (WAI) and water solubility index (WSI) were performed following the methodology described by ANDERSON et al. (1969). The sample (1 g) was mixture with 10 mL of distillated water, shaked smoothly for 30 min at 25 °C in a Dubnoff water bath NT 232 (Novatecnica, Piracicaba, Brazil) and centrifuged at 3000 *g* for 15 min in a centrifuge Universal 320R (Hettich, Tuttingen, Germany).The supernatant was drying in an air circulating oven (WTB Binder, Tuttlinger, Germany) at 105 °C for 4 h, this data is used as the weight of the water soluble matter, and the remaining gel formed in the test tube was also weighting. WSI and WAI were calculated by using the following equations:

$$WSI = (Water\ soluble\ matter\ (g))x100/(Dry\ sample\ (g)) \quad 7$$

$$WAI = (Formed\ gel)/(Dry\ sample\ (g)) \quad 8$$

Pasting viscosity was carried out on a Rapid Visco Analyser (RVA, Newport Scientific Pty Ltd., Warriewood, NSW, Australia), according the methodology described by Whalen et al. (1997). The sample (3 g adjusted at 14% of moisture) was placed in a RVA aluminum cup, mixture with 25 g of distillated water and run the configuration profile as follow: mixing at 160 rpm at 25 °C for 2 min, heating up to 95 °C at 14 °C/min rate, holded for 4 min, cooled to 25 °C in 5 min (at the same rate), completing a total time of 20 min. The results obtained from the paste curve were cold viscosity 25 °C, (CV) (maximum viscosity achieved at 25 °C), Peak viscosity at 95 °C (PV) (maximum viscosity reading during the heating cycle at 95 °C), minimum viscosity after heating (MV), breakdown viscosity (PV-MV), final viscosity (FV) and setback viscosity (FV-MV).

Sensory analysis

The sensory tests were performed by 101 untrained consumers (40 males and 61 females), which included graduate and post-graduate students, researches and employees that were recruited at Embrapa Industria de Alimentos. Ethical approval was provided by The Human Ethics Research Committee at Federal University of Minas Gerais, Brazil, approved this study (N° 03591312.0.0000.5149). The consumer socioeconomic and consumption of cereal breakfast information were taken from participants. Then, the sorghum cereals were served (2-4 g) in a coded (three number) plastic cups (35 mL of capacity). Water (100 mL) was provided to clean the mouth between samples, the samples were randomly presented for each consumer. Sensory evaluation was carried out and the panelists were seated in individual booths at room temperature with daylight-equivalent lighting.

General sensory acceptance (GSA) was evaluated by using a 9-poit hedonic scale (dislike extremely = 1; dislike very much = 2; dislike moderately = 3; dislike slightly = 4; neither like nor dislike = 5; like slightly = 6; like moderately = 7; like very much = 8; like extremely = 9).

Sensory attributes were evaluated using 25 characteristics from CATA question, which were previously defined by 12 panelist. randomized among panelist and products. Finally, the participants were asked about buying intention of the cereals by using a five point scale were: definitively I do not buying = 1; maybe I do not buying = 2; maybe I buying or not = 3; maybe I buying = 4; definitively I buying =5. The data was collecting using the software Fizz (Biosystemes, França).

Statistical Data analysis

It was used a single factor design performing the analysis of variance (one-way ANOVA) to determinate if there were differences among the six sorghum genotypes, and Tukey test (α = 0.05). Principal component analysis (PCA) was running after data satirized to avoid the effect of the different magnitude order and units of the variables. It was applied to understand the correlation between variables and samples. Hierarchical Clustering on Principle Components (HCPC) was performed to form samples groups with similar characteristics, HCPC is a clustering technic making from the PCA results, the algorithm of the HCPC use Euclidian distances and Ward´s criterion. Cochran's Q test was performed for to identify significant attributes between samples on the each CATA attribute. Correspondence Analysis (CA) on attribute frequency from CATA question to obtain maps representing the attributes that characterized each sample. Finally the multi factor analysis was performed in order to study the effect of all variables (qualitative and quantitate), for physic-chemical, antioxidant properties and sensory responses. All analyses were performed using the software R for statistical computing, version 3.2.4 (CORE_TEAM, 2017) and the FactoMineR package version 1.32.

RESULTS AND DISCUSSIONS

Characterization of sorghum genotypes

There was a high variation (g/100g) in the contents of moisture, ash, protein, dietary fiber, fat, carbohydrates and calories (kcal/g) among the six whole flour sorghum genotypes (Table 2), varied respectively, from 9.689 to 12.29, 1.31 and 1.71, 9.09 to 9.89, 2.26 and 2,95, 11.38 and 21.22 and 264.04 to 318.02. These values are similar to other reports (VARGAS-SOLÓRZANO et al., 2014; QUEIROZ et al., 2015; HOLMES et al., 2017), the variation could be due genotype, soil, and weather.

Table 2. Physicochemical and morphological measurements for the six sorghum genotypes.

Characteristic	Sorghum genotype					
	BR305	BRS330	BRS373	BRS501	CMSS005	SC319
Moisture (g/100g)	12.22 ± 0.06[a]	12.03 ± 0.01[a]	12.24 ± 0.12[a]	9.68 ± 0.01[c]	10.74 ± 0.1[b]	12.29 ± 0.02[a]
Ash (g/100g)	1.41 ± 0.08[c]	1.31 ± 0.09[c]	1.4 ± 0.07[c]	1.91 ± 0.02[a]	1.71 ± 0.04[ab]	1.52 ± 0.04[bc]
Protein (g/100g)	9.89 ± 0.08[a]	9.2 ± 0.08[bc]	9.09 ± 0.24[c]	9.86 ± 0.12[a]	9.86 ± 0.04[a]	9.66 ± 0.08[ab]
Fat (g/100g)	2.63 ± 0.25[ab]	2.26 ± 0.54[b]	2.72 ± 0.12[ab]	3.52 ± 0.04[a]	2.66 ± 0.23[ab]	2.95 ± 0.01[ab]
Dietary fiber [1]	14.44	11.63	10.84	12.31	11.38	16.73
Carbohydrate [2]	59.39	63.20	53.12	47.82	63.89	56.82
Calories (Kcal/g)	300.87	311.41	274.2	262.04	318.02	292.67
Morphologycal measurements						
XY area [3]	10.39 ± 1.23[d]	10.91 ± 1.64[c]	12.12 ± 1.63[a]	9.2 ± 0.53[e]	11.4 ± 1.19[b]	9.95 ± 1.03[d]
XY perimeter [4]	12.23 ± 0.73[c]	13.02 ± 1.04[ab]	13.3 ± 0.91[a]	11.64 ± 0.34[d]	12.77 ± 0.65[b]	12.19 ± 0.64[c]
X axis (mm)	3.83 ± 0.24[c]	3.93 ± 0.27[b]	4.26 ± 0.29[a]	3.71 ± 0.11[d]	3.94 ± 0.2[b]	3.91 ± 0.21[bc]
Y axis (mm)	3.45 ± 0.23[b]	3.51 ± 0.3[b]	3.61 ± 0.26[a]	3.15 ± 0.13[c]	3.67 ± 0.22[a]	3.24 ± 0.19[c]
XY circularity	0.87 ± 0.01[a]	0.81 ± 0.03[d]	0.86 ± 0.01[b]	0.85 ± 0.02[b]	0.88 ± 0.01[a]	0.84 ± 0.01[c]
XZ area [3]	8.3 ± 1.09[ab]	7.19 ± 1.15[cd]	7.94 ± 1.19[b]	6.98 ± 0.56[d]	8.36 ± 1.22[a]	7.54 ± 1.09[c]
XZ perimeter [4]	11.62 ± 0.76[a]	10.9 ± 0.81[b]	11.58 ± 0.82[a]	10.41 ± 0.35[c]	11.4 ± 0.7[a]	11.4 ± 0.7[a]
Z axis (mm)	2.7 ± 0.24[a]	2.37 ± 0.25[b]	2.4 ± 0.25[b]	2.42 ± 0.14[b]	2.65 ± 0.31[a]	2.41 ± 0.26[b]
XZ circularity	0.77 ± 0.04[b]	0.76 ± 0.03[c]	0.74 ± 0.04[d]	0.81 ± 0.02[a]	0.8 ± 0.03[a]	0.73 ± 0.04[d]
Sphericity	0.86 ± 0.03[a]	0.81 ± 0.03[b]	0.78 ± 0.03[d]	0.82 ± 0.02[b]	0.86 ± 0.03[a]	0.8 ± 0.03[c]
Inside characteristics						
Germ area (mm^2)	1.55 ± 0.29[a]	1.33 ± 0.24[ab]	1.33 ± 0.2[ab]	1.18 ± 0.26[b]	1.18 ± 0.26[b]	1.26 ± 0.09[b]
White area (mm^2)	3.14 ± 0.96[bc]	3.62 ± 0.93[b]	4.08 ± 0.7[b]	3.03 ± 0.8[bc]	3.03 ± 0.8[bc]	6.15 ± 1.04[a]

Values are Mean ± standard derivation (g/100g) n = 2, different letters within the same row indicates statistic differences ($p<0.05$). 1: Analyses without repetitions, 2: Determinate by differences, 3: expressed in mm^2, 4: expressed in mm. Morphologycal measurements were made using n=130.

Sorghum BRS501 (white) had the lower amount of moisture, carbohydrate and calories, contrary, the other white sorghum (CMSS005) presented the great value of carbohydrates and calories. According to YOUSIF et al. (2012), the carbohydrate is the major component in sorghum grain, nevertheless, appears had less digestibility than other cereals.

The genotype SC319, had bigger amount of fat, regarding to protein content the BR305 presented major amount (9.89). Sorghum SC319 and BR305 presented the higher fiber amount, 16.73 and 14.44 respectively (Table 2) which could be an interested genotype to develop high fiber content products to reduce the risk associated to low fiber daily consume (CHÁVEZ et al., 2017). According to Queiroz et al. (2018), products with Sorghum may be considered a good source of protein, and cloud contribute to the achievement fiber daily intake, additionally to the fact that those products are safe for celiac due sorghum is a gluten free cereal (CIACCI et al., 2007; LOHANI ; K., 2017).

Shape characteristics

The picture for digital analysis have an excellent quality (6000x4000 pixels), resulting in a imagej scale of 41.6 pixel/mm, in other words, each pixel had 0.024 mm of precision, while an analogy vernier reach 0,01 mm. Since, the image analyses uses 2-D imagines, it cannot directly quantify volume of the particles directly (KUMARA et al., 2012), however it is possible to measure the three axes (and calculate the sphericity) changing manually the grains position. Regarding to shape characteristics, the sorghum genotype BRS373 had the bigger values of transverse area (Table 2), transverse perimeter, and X axis (12.12 mm^2, 13.3 mm and 4.26 mm respectively). The XY circularity varied from 0.81 mm (BRS330) to 0.88 mm (BRS501), on the other hand, the XZ circularity presented less values and higher variation (0.73 – 0.80 mm), been sorghum BRS373 and SC319 the small values.

These differences could also be related to quantity of the mass in the material, thus, the mass (weight) grain is helpful relationships amount the variables and samples, therefore, in the correlogram (Figure 2a), weight have a correlation value of r = 0.83 with XZ circularity, which, in turns, according to Mukaka (2012), indicate a high positive correlation, the author, proposed an interpretation rule for r values (Figure 2b) in laboratory research areas like medicine and could be appropriate use in food experiments due both research areas are rigorousness closed. The sphericity presented high positive correlation with Z axis and XZ area (0.89 and 0.81 respectively). On the other hand, sphericity indicates how close to a sphere is a grain, the sphericity had a positive high correlation (r = 0.89) with the Z axis, due in the XY plane all genotype were close to a circle (XY circularity ranged from 0.81 to 0.88), but XZ plane presented less values of XZ circularity.

On the other hand, there is a high negative correlation (r = -0.87) between XZ circularity and white area in the half grain, it means that, the flatter the grain the bigger the white area in a half grain, that means that theses grains has less symmetric shape BRS330 and BRS373 (Table 2 and Figure 2c and 2d), it could diminish their acceptance in the market, due the choice and the acceptance are also determined by the shape of the grains (BITJOKA et al., 2015), This show the importance of the computer image analyses, because according to Igathinathane et al. (2009), it provide an fast, economic, appropriate, objective and consistent assessment of different products.

In the same idea, PCA provide an ease view instead complexes Tables, e.g. BRS501 is alone (Figure 2d), this could be explain because these genotype had the smaller values in the X, Y and Z axes (Table 2). As was mentioned above BRS330 and BRS373 are closed. CMSS005 and BR305 formed another group.

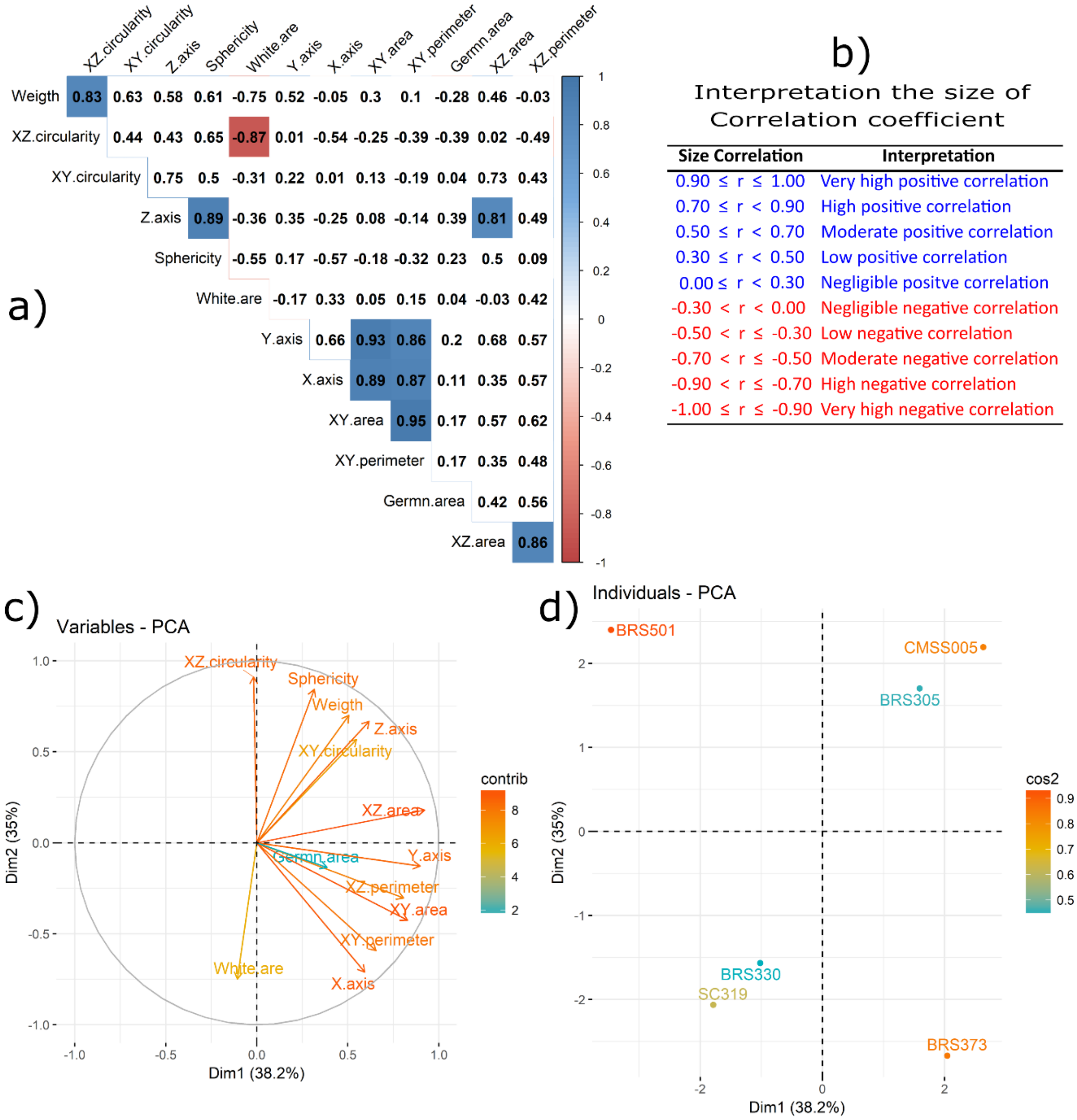
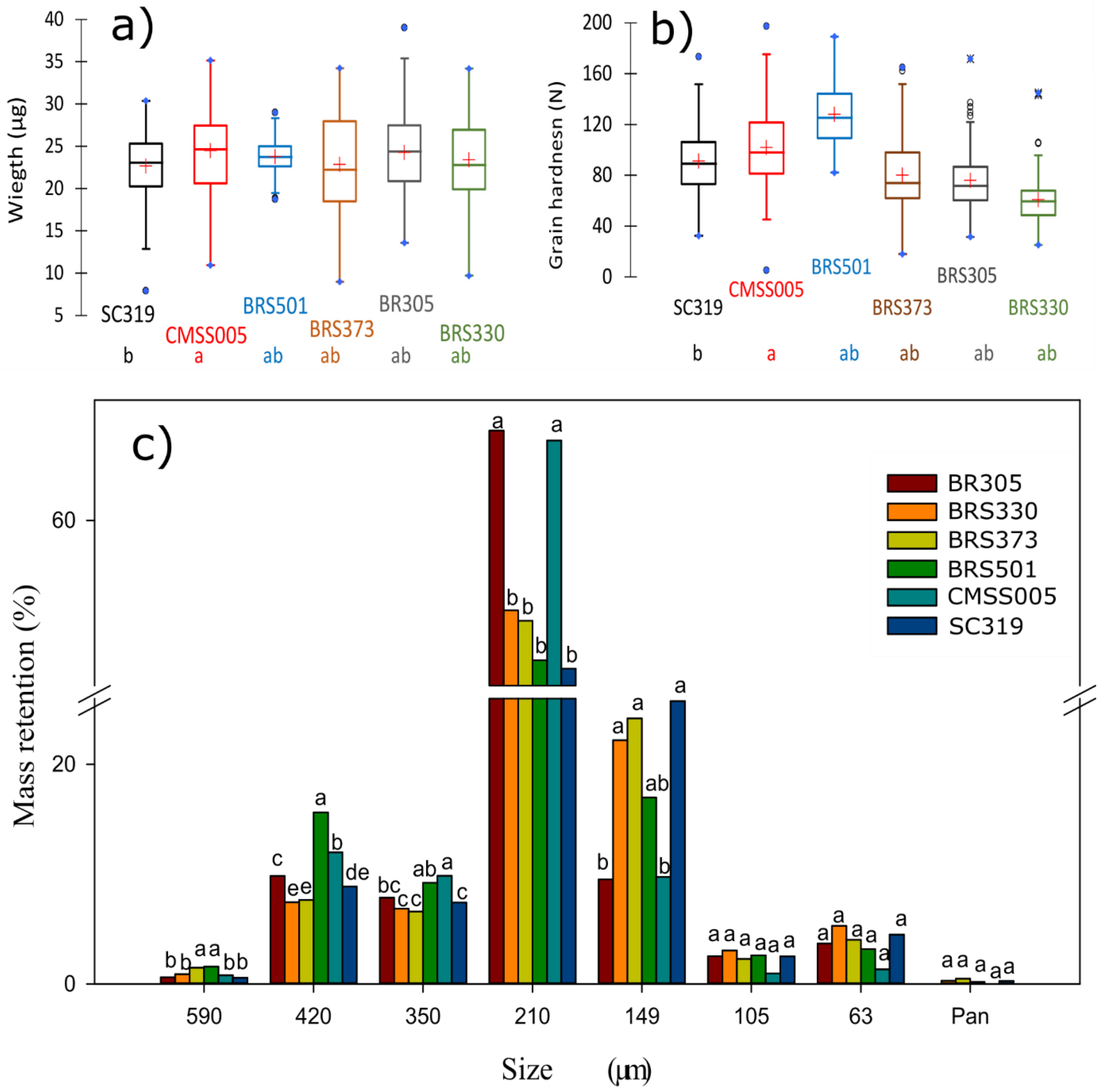


Figure 2. Multivariate analyses from shape characteristics of six sorghum genotypes; a) Pearson correlation matrix (Correlogram), numbers in Table body indicates the Pearson correlation value (r), numbers without background have no significant correlation (p>0.05), number with red or blue background in Table body indicate negative and positive significant correlation (p<0.05) respectively; b) An interpretation of the r value, proposed by Mukaka (2012); c) Principal component analyses (PCA) for variables and d) PCA for samples.

The genotype weight (Figure 3a) ranged from 22.62 to 24.66 µg (SC319 and CMSS005 respectively), and the harness (Figure 3b) varied from 57.3 to 124.4 N (BRS330 and BRS501 respectively). Sorghum BRS501 presented high value of hardness ($p<0.05$) even when it had less weight ($p<0.05$), this could be due BRS501 presented lower weight range (Figure 3a), having more uniform grains, other factor that could influences in the hardness was the less moisture (Table 2), high protein, ash and carbohydrates content of the BRS501.

On the other hand, low values of hardness were presented by BRS330, BR305 and BRS373, which may be attributed to the larger white region which corresponds the floury starch rich grain endocarp (Table 2). Regarding the size distribution of the retained flour fraction, the differences (Figure 3c) in the mass retention (%), this can be explain by the differences in chemical composition, as previously reported by other authors (CARVALHO et al., 2010; VARGAS-SOLÓRZANO et al., 2014; CHÁVEZ et al., 2017).



Size (Ym)

Figure 3. Weight (a) and hardness, different small letters indicates statistical differences among samples ($p<0.05$) (b) of the sorghum grain and the size distribution, same small letters means no statistical differences ($p>0.05$) (c) of the flour obtained from the whole grains, different letters indicates statistical differences ($p<0.05$).

Antioxidants and color of the six grains

Sorghum BR305 had the biggest values of antioxidant properties (Table 3) with 129.28 µmol TE/g, 98.96 µmol TE/g, 16.06 mg GAE/g and 4.39 mg CE/100g respectively for DPPH, ABTS, TPC and TCT. Sorghum SC319 was the second genotype with high antioxidant properties having closer values but with statistical differences ($p<0.05$) for almost all antioxidant properties with the exception of TPC content ($p>0.05$). It is known that this cereal has the highest levels of antioxidants, when compared with other cereals (RAGAEE et al., 2006; AFIFY et al., 2012; CARDOSO et al., 2015; CHÁVEZ et al., 2017; LOHANI, 2017). The greatest antioxidant capacity level was found in BR305 and SC319 is related to tannins and phenolic contents (SALAWU et al., 2014; ADARKWAH-YIADOM; DUODU, 2017). According to Afify et al. (2012), the phenolic compound may have structural features that favor radical scavenging and metal chelation, increasing their antioxidant effects.

White sorghum pericarp (BRS501 and CMSS005) presented the lowest antioxidant properties, due the absence of pigment compounds in their pericarp (LLOPART; DRAGO, 2016). BRS330 and BRS373 showed higher antioxidant capacity than white genotypes, although lower than BR305 and SC319. The genotypes BRS330, BRS373, BR305 and SC319 presented similar pericarp color varying from red to brown, that was detected as small differences in color parameters with no significant differences (p<0.05) (Table 3), when compared to white sorghum genotypes.

Table 3. Antioxidant and color values for the six sorghum genotypes.

Characteristic	Sorghum genotype					
	BR305	BRS330	BRS373	BRS501	CMSS005	SC319
			Antioxidant properties			
DPPH (µmol TE/g)	129.28 ± 3.98[a]	10.29 ± 0.19[c]	8.03 ± 0.21[c]	3.83 ± 0.3[c]	5.12 ± 0.25[c]	120.94 ± 6.17[b]
ABTS (µmol TE/g)	98.96 ± 0.62[a]	12.93 ± 0.63[c]	11.63 ± 0.78[c]	4.13 ± 0.54[d]	7.28 ± 0.26[d]	94.03 ± 3.59[b]
TPC (mg GAE)/g)	16.06 ± 3.8[a]	2.55 ± 0.09[b]	1.97 ± 0.04[b]	0.39 ± 0.08[b]	1.09 ± 0.27[b]	13.7 ± 1.09[a]
TCT (mg CE)/100g)	4.39 ± 0.11[a]	---	---	---	---	1.72 ± 0.04[b]
			Grain color			
L	45.92 ± 0.96[b]	45.62 ± 2.16[b]	44.19 ± 1.1[b]	61.88 ± 2.05[a]	60.3 ± 1.31[a]	43.19 ± 1.87[b]
a*	8.08 ± 0.41[a]	8.19 ± 0.48[a]	7.15 ± 0.8[ab]	3.58 ± 0.67[c]	4.54 ± 0.45[c]	6.14 ± 0.83[b]
b*	9.05 ± 1.05[b]	7.24 ± 1.12[bc]	5.98 ± 0.7[cd]	14.15 ± 1.24[a]	16.19 ± 0.63[a]	4.93 ± 1.71[d]
C	12.14 ± 1.02[c]	10.95 ± 0.99[cd]	9.32 ± 1.05[de]	14.62 ± 1.09[b]	16.81 ± 0.62[a]	7.94 ± 1.54[e]
H	48.09 ± 2.22[b]	41.25 ± 3.68[bc]	39.92 ± 0.92[bc]	75.65 ± 3.56[a]	74.32 ± 1.59[a]	37.63 ± 8.4[c]

Values are Mean ± standard derivation n = 3, different letters within the same row indicates statistic differences by tukey test (p<0.05).

In this way the differences in antioxidant properties od sorghum with similar visible colors, could be explain because the pericarp color and its intensity is not necessary an indicator of the presence of bioactivity compound, as was reported by Dykes; Rooney (2006). The highest values of luminosity (L) was obtained by BRS501 and CMSS005 with respectively 61.88 and 60.30 differing for the others (p<0.05), in sync with the lowers a* values (3.58 and 4.54 respectively).

Sorghum has been extensively study regarding its functional properties, different authors reported considerable phytochemistry compound with health promoting properties (ADARKWAH-YIADOM; DUODU, 2017; HARRON et al., 2017), those secondary metabolites varied from tannins, anthocyanins, carotenoids, flavonoids, phenolic acids such as gallic acid, vanillic acid, chlorogenic acid, caffeic acid, syringic acid, p-coumaric acid, ferulic acid, sinapic acid, o-coumaric acid, (AWIKA et al., 2003; VALLABHANENI et al., 2010; KHAN et al., 2013; ADARKWAH-YIADOM; DUODU, 2017; CHÁVEZ et al., 2017; HARRON et al., 2017). The profile of functional compounds also depend on genetic factors that the color and thickness of different gran parts such as pericarp, presence of pigmented testa, etc. (CARDOSO et al., 2015). Epidemiological studies actively suggested that rich functional compound diets, based on whole grains could play a key role in reduction or prevention of chronic diseases (AWIKA et al., 2003; AWIKA et al., 2009; ADARKWAH-YIADOM; DUODU, 2017).

Expanded characterization

Extruded of white sorghum (BRS501 and CMSS005) genotypes showed largest values of SEI, with values of 7.21 and 6.67, respectively (Table 4), followed, in this order, BRS330, BRS373, SC319 and BR305. Thus, SEI presented a very high and negative correlation (Figure 4c) with TPC (r=-0.90), and high negative correlation with DPPH and ABTS (r values of -0.87 and -0.89 respectively). This occurred probably due to the presence of tannins and other phytochemicals, as observed by the work of Vargas-Solorzano who found that tannin sorghum genotypes produced extrudates with lower SEI values.

Regarding texture (Table 4), hardness did not show significant differences ($p<0.05$) for all extruded samples, which ranged from 275.56 to 388.24 N. Thus, the expanded from BR305 and SC319 had the greatest values with 371.14 N and 388.24 N respectively, while the extrudes from BRS501 and CMSS005 obtained lower values, it could be explain by the presence of functional compounds and corroborated with the correlogram (Figure 4c), in which cereal hardness had high positive correlation with TPC, DPPH and ABTS (0.89, 0.88 and 0.89, respectively).

Table 4. Functional properties of six sorghum genotypes extrudates: sectional expansion index (SEI), texture, past viscosity readings and water absorption and water solubility indices.

Characteristic	BR305	BRS330	BRS373	BRS501	CMSS005	SC319
SEI	3.84 ± 0.44^{d}	5.56 ± 0.51^{c}	5.35 ± 0.49^{c}	7.21 ± 0.68^{a}	6.57 ± 0.78^{b}	4.12 ± 0.52^{d}
CerHard (N)	371.14 ± 18.50^{b}	335.54 ± 19.23^{c}	323.00 ± 13.12^{d}	275.56 ± 14.16^{f}	303.06 ± 15.01^{e}	388.24 ± 16.13^{a}
CerCrip (N°)	143.09 ± 10.52^{c}	157.17 ± 9.22^{b}	189.71 ± 10.12^{a}	159.77 ± 6.98^{b}	153.60 ± 8.88^{b}	140.71 ± 8.72^{c}
CV	113.00 ± 32.23^{abc}	85.00 ± 9.54^{bc}	84.67 ± 6.81^{bc}	132.67 ± 8.08^{a}	123.67 ± 2.52^{ab}	73.00 ± 6.24^{c}
PV	82.67 ± 31.79^{a}	72.00 ± 1.00^{ab}	83.67 ± 6.43^{a}	42.33 ± 4.93^{b}	48.67 ± 0.58^{ab}	52.67 ± 3.21^{ab}
mV	50.33 ± 23.44^{a}	36.00 ± 2.00^{abc}	44.67 ± 2.08^{ab}	12.33 ± 4.04^{c}	14.33 ± 2.52^{c}	20.67 ± 5.13^{bc}
Breakdown	32.33 ± 8.39^{a}	36.00 ± 1.00^{a}	39.00 ± 4.58^{a}	30.00 ± 1.00^{a}	34.33 ± 2.52^{a}	32.00 ± 2.65^{a}
FV	78.00 ± 28.16^{a}	63.33 ± 3.06^{ab}	62.00 ± 1.73^{ab}	40.67 ± 2.89^{b}	44.33 ± 2.31^{b}	45.00 ± 8.54^{ab}
Setback	45.67 ± 20.13^{a}	27.33 ± 3.51^{ab}	23.00 ± 3.46^{ab}	10.67 ± 2.08^{b}	10.00 ± 4.58^{b}	13.00 ± 11.14^{b}
WAI	3.55 ± 0.02^{c}	3.95 ± 0.17^{ab}	3.96 ± 0.2^{ab}	4 ± 0.06^{a}	4.06 ± 0.07^{a}	3.75 ± 0.06b^{c}
WSI	19.43 ± 0.51^{c}	17.21 ± 0.63^{d}	15.14 ± 0.61^{e}	24.92 ± 0.63^{a}	22.59 ± 1.29^{b}	18.91 ± 0.39^{c}

Values are Mean ± standard derivation n = 3, different letters in the same row means statistical differences by tukey test ($p<0.05$), CerHard: cereal hardness, CerCrip: cereal crispness. Cold viscosity 25°C (CV). Peak viscosity at 95°C (PV). Maximum viscosity reading during the heating cycle at 95°C. Minimum viscosity after heating (mV), breakdown viscosity (PV-MV), final viscosity (FV) and setback viscosity (FV-MV), WAI, Water absorption index and WSI water solubility index.

The past viscosity meassurements (Table 4) showed very low viscosity values due to the extrusion process which led to high starch breakdown. CV ranged from 73.00 to 132,67 cP, while Pv varied between 42.33 and 83.67 cP, in the other hand, mV values were between 12.33 to 50.33, Breakdown was only one that present no differences ($p>0.05$) ranged from 30.00 to 39.00 cP, the FV varied from 40.64 to 78.00 cP and the Setback with values from 10.00 to 45.67 cP). The extensive starch conversion of sorghum flours caused by extrusion was also reported by other authors (VARGAS-SOLÓRZANO et al., 2014; CHÁVEZ et al., 2017; NASCIMENTO et al., 2017).

PCA (Figure 4a and 4b) explained almost 80% of the data variability, which indicates that the extruded responses would be affected by the grain characteristics. From Figure 4b, it can be seen that sorghum genotypes SC319 and BR305 showed the highest values of antioxidant capacity and extrudates hardness, whereas BRS501 and CMCC005 had the highest values of luminosity (L) and hue angle (h), which was expected, since the later genotypes present white pericarp.

Based on their pericarp color, antioxidant and extruded characteristic of the six sorghum were grouped into three clusters by PCA (Figure 4b), which corroborates with HCPC analyses displayed in Figure 4d. By looking at Figure 4d, BRS501 and CMSS005 (white pericarp) showed low antioxidant properties, followed by the second group (red cluster) formed by colored sorghum with slight higher antioxidant properties (BRS330 and BRS373), and then the group formed by sorghums, SC319 and BR305, with high antioxidant properties. The highest consumption frequency was “rarely” (50.5%), followed by “often” 29% and “never” (15.8%). Different letters in the same row indicate differences at 5%.

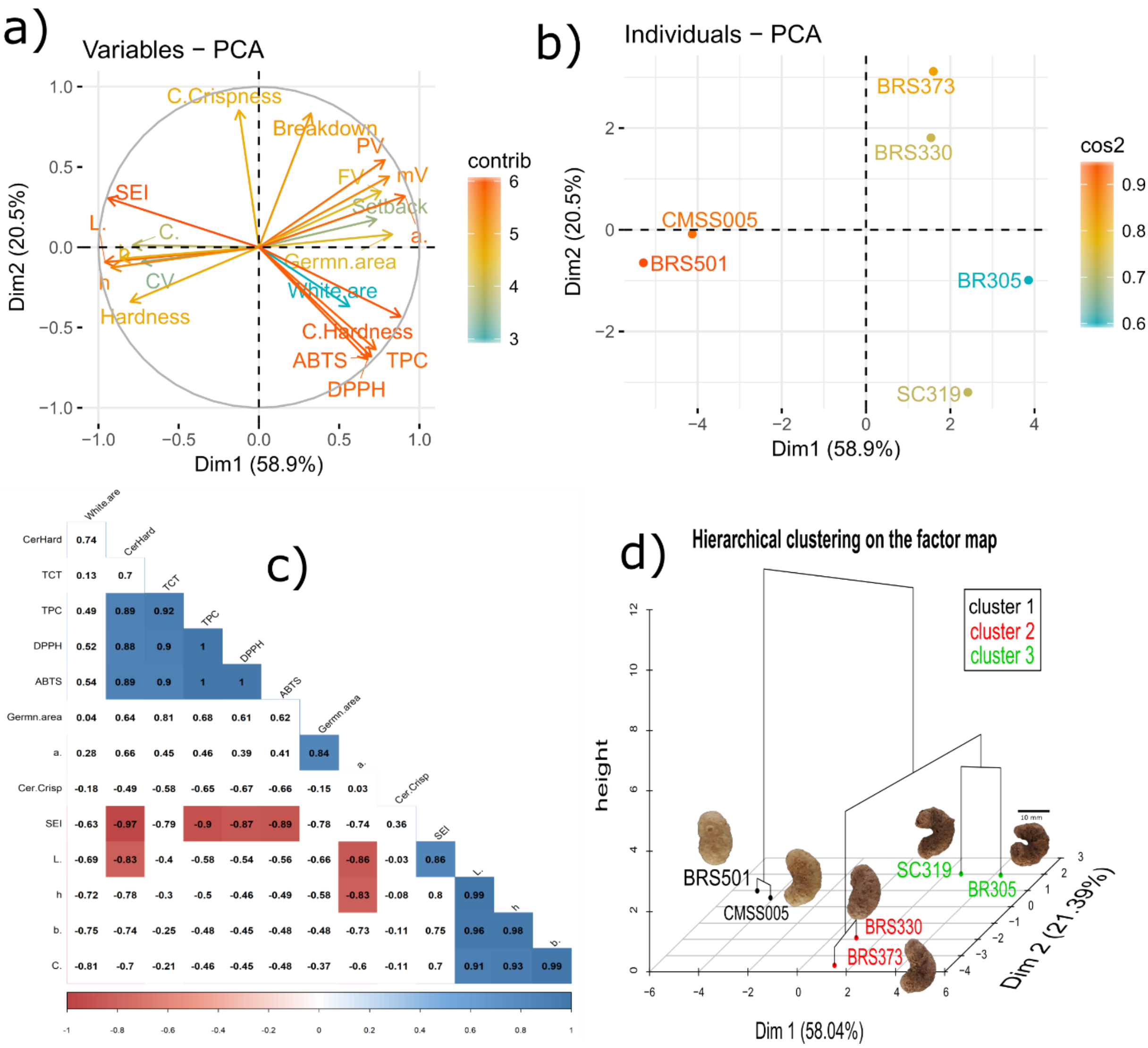


Figure 4. Multivariate analyses from color, antioxidant properties and extrusion evaluations for six sorghum genotypes; a) Principal component analyses (PCA) for variables; b) PCA for samples; c) Correlogram, numbers (r values) without background have no significant Pearson correlation (p>0.05); numbers with red or blue background in Table body indicate negative and positive significant correlation (p<0.05) respectively; d) Hierarchical clustering from principal components.

Sensory results

Participant characteristics are presented in Table 5. They were 60 % of female, aged from 18 to 45 years old (70.3%), the highest education level was post-graduation (~67%) and the predominant income was up to 20 minimum wage. Two segments of consumers (Table 4 and Figure 5a and Figure 5b) were identified, group 1 with 72 consumers and group 2 with 29, with differences in sample scores, but both groups followed the same profile. The second group have lower scores among all samples, this could be explain because the second group had the double of people percentage that "never" consume expanded (24.1%).

Four samples had no significant differences (p>0.05) regarding to sensory acceptance (Table 6 and Figure 5), BRS373, CMSS005, BR305, BRS330 and BRS501 obtained GSA values of 5.3, 5.3, 5.2 and 5.0 respectively. On the other hand tannin contain samples SC319 and BR305 presented the lowers values of sensory acceptance, thus SC319 and BR305 obtained values of 4.5 and 4.3 respectively (with no significant differences between then). These results are contrast by the reported that high-tannin sorghum is responsible for a little increase in bitterness, not detectable by all consumers (DAIBER, 1975; HOLMES et al., 2017). Regarding to the buying intention (Table 6) it was observed that the group 2 had a higher percentage of people how opinion that "Definitively do not buying" >75% for all samples. Regarding to the buying intention (Table 6), there was a ~31% (including all samples) that mention "definitively do not buying", these could be attribute to the lack of seasoning, but is important to note that the second group of consumers had a very high percentage of "definitively do not buying" or "maybe do not buying", this may be related that this groups was formed by consumer with less expanded snack consumption habit (Table 5 and Figure 5).

Table 5. Participants (n=101) socio-demographic profile, expressed in %

Category	Total *	Group 1 ** (n=72)	Group 2 *** (n=29)
Gender			
Female	60.4	59.7[a]	62.1[a]
Male	39.6	40.3[a]	37.9[b]
Age group (years)			
18-25	17.8	19.4[a]	13.8[b]
26-35	23.8	22.2[a]	27.6[b]
36-45	28.7	27.8[a]	31.0[a]
46-55	12.9	12.5[a]	13.8[a]
56-65	12.9	12.5[a]	13.8[a]
>65	4.0	5.6[a]	0.0[b]
Education			
Incomplete fundamental school	1.0	1.4[a]	0.0[a]
Complete fundamental school	1.0	0.0[a]	3.4[b]
Incomplete high school	4.0	4.2[a]	0.0[b]
Complete high school	3.0	4.2[a]	3.4[a]
Incomplete graduation	15.8	18.1[a]	10.3[b]
Complete graduation	7.9	5.6[a]	13.8[b]
Post-graduation	67.3	66.7[a]	69.0[a]
Income minimum Brazilian wage (MBW)* = R$954.0**			
1 to 5 MBW	29.7	34.7[a]	17.2[b]
>5 to 10 MBW	14.9	12.5[a]	20.7[b]
>10 to 20 MBW	34.7	31.9[a]	41.4[a]
>20 to 30 MBW	16.8	18.1[a]	13.8[b]
>30 MBW	4.0	2.8[a]	6.9[b]
Frequency consumption of expanded cereal			
Never	15.8	12.5[a]	24.1[b]
Rarely	50.5	56.9[a]	34.5[b]
Weekly	4.0	4.2[a]	3.4[a]
Often	29.7	26.4[a]	37.9[b]
Daily	0.0	0.0	0.0

* % of the total (n=101), ** % inside each group, ** In Brazilian currency (Real). The groups were made by hierarchical clustering from sensorial acceptance. Different letters in the same row indicates statistical differences (p<0.05) by t test.

Table 6. Multiple mean corporation for general acceptance and buying intention.

General Acceptation (9 point scale)	Treatments: Expanded making from sorghum genotypes					
	BRS501	BRS330	BR305	CMSS005	BRS373	SC319
Total (n = 101)	5.0 ± 1.8[A]	5.2 ± 1.9[A]	4.3 ± 1.8[B]	5.3 ± 1.7[A]	5.3 ± 1.9[A]	4.5 ± 1.8[B]
Group 1 (n = 72)	5.7 ± 1.4[a]	6.1 ± 1.4[a]	5.1 ± 1.4[a]	6.0 ± 1.4[a]	6.1 ± 1.4[a]	5.1 ± 1.4[a]
Group 2 (n = 29)	3.5 ± 1.7[b]	3.1 ± 1.4[b]	2.3 ± 1.2[b]	3.7 ± 1.3[b]	3.2 ± 1.4[b]	2.9 ± 1.7[b]

Buying intention (%), consumers for total n=101, for group 1 n=72 and for group 2 n= 29

Treatment	Groups	Definitively do not buying	Maybe do not buying	Maybe buying or not	Maybe buying	Definitively buying
BRS501	Total	40.6	16.8	19.8	18.8	4.0
BRS501	Group 1	25.4[a]	21.1[a]	23.9[a]	25.4[a]	4.2[a]
BRS501	Group 2	75.9[b]	6.9[b]	10.3[b]	3.4[b]	3.4[a]
BRS330	Total	35.6	20.8	19.8	15.8	7.9
BRS330	Group 1	18.3[a]	22.5[a]	26.8[a]	22.5[a]	9.9[a]
BRS330	Group 2	75.9[b]	17.2[b]	3.4[b]	0.0[b]	3.4[b]
BR305	Total	49.5	29.7	10.9	7.9	2.0
BR305	Group 1	33.8[a]	39.4[a]	14.1[a]	11.3[a]	1.4[a]
BR305	Group 2	86.2[b]	6.9[b]	3.4[b]	0.0[b]	3.4[a]
CMSS005	Total	24.8	27.7	23.8	17.8	5.9
CMSS005	Group 1	15.5[a]	21.1[a]	32.4[a]	23.9[a]	7.0[a]
CMSS005	Group 2	44.8[b]	44.8[b]	3.4[b]	3.4[b]	3.4[b]
BRS373	Total	34.7	21.8	18.8	18.8	5.9
BRS373	Group 1	19.7[a]	22.5[a]	22.5[a]	26.8[a]	8.5[a]
BRS373	Group 2	80.3[b]	20.7[a]	10.3[b]	0.0[b]	69.0[b]
SC319	Total	44.6	25.7	18.8	7.9	3.0
SC319	Group 1	31.0[a]	29.6[a]	25.4[a]	11.3[a]	2.8[a]
SC319	Group 2	75.9[b]	17.2[b]	3.4[b]	0.0[b]	3.4[a]

Capital letters in the same row indicate significant differences among expanded from different sorghum genotypes, small letters in the same column means differences ($p<0.05$) by t test. The groups were made by hierarchical clustering from sensorial acceptance.

According to Anunciação et al. (2017) and Queiroz et al. (2018), the mean acceptance score, could be classified as follow: rejection (≤ 4.0), indifference (5.0 - 5.9) and acceptance (≥ 6.0) of the products. Thus, in this study, the highest values (5.3) means indifference, these results could suggested that Brazilians would like seasoning expanded snacks (as will be discussed later, in CATA test), and the expanded in these study did not use any seasoning like sugar, salt, or whatever. On the other way, Anunciação et al. (2017), reported a high percent of acceptance (70.59) for sorghum expanded made from sorghum genotype BR305, because, they used seasonings in the experiment (10% sugar and 0.5% salt).

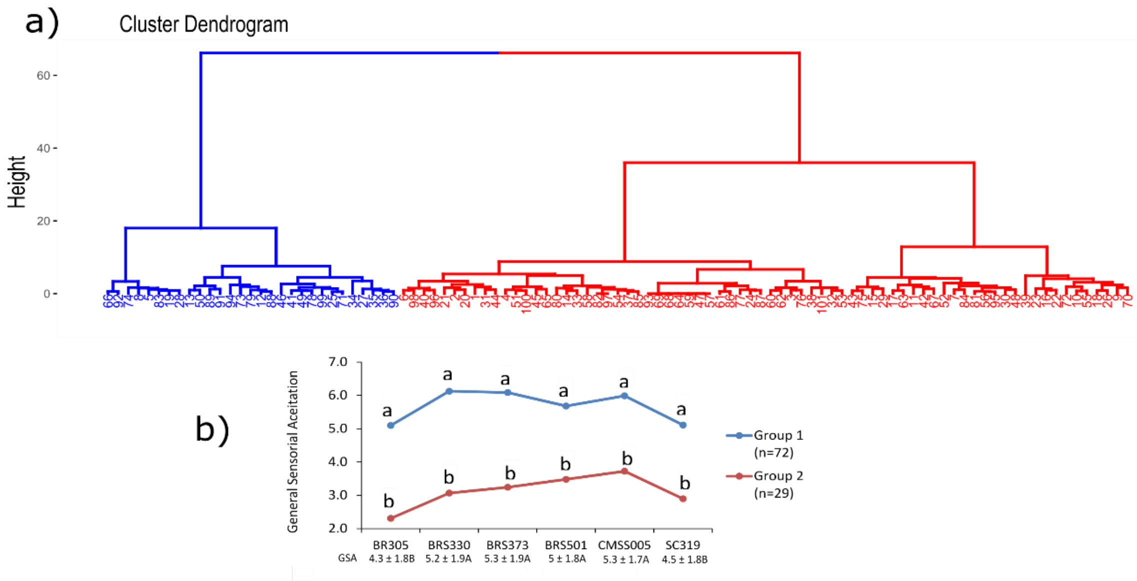


Figure 5. Groups formed by hierarchical cluster analyses of the consumers (a), General sensory acceptance for both total and groups (b), different small letters in the same column means differences between groups ($p<0.05$), the same capital letter among sorghum genotypes indicate similarity in the general sensory acceptation for consumers ($p>0.05$).

There were 25 terms used in CATA question which were previously determinate by a preliminary test with consumers, those terms are detail in Table 7, the average percent of attributes using by the consumers was 28% ranged from 4% to 60%. Sweet flavor, Hard and snack flavor were the least used. Without salt, without seasoning Sticky on teeth and without flavor were the most used, this could be the reason for the low sensory acceptance, as was mention above. In other study with sorghum snack the acceptance were better (>6,0) due the authors used sugar in the snack formulations (ANUNCIAÇÃO et al., 2017),. In CATA question, both, least and more used tern have no significant influence ($p>0.05$) to differentiate the samples. On the other hand, Characteristic taste, Bad taste, snacks taste, Nice taste, Bitter taste, Crunchy, Slightly crunchy, Slightly expanded, Expanded, Dark color, Light color, and Bright brown color, were the attributes that were significant ($p<0.05$).

In CATA (explain 94.8% of the variability by Dim1 and Dim2), expanded making from tannin sorghum (BR305 and SC319) have were more related to bad flavor, burnt flavor, little expanded, little crunchy and dark color (Figure 6a), this could be explain because those attributes had higher frequency in attributes for tannin samples, but the attribute dark color was not a rejection factor because there were another samples with dark color with more GSA than tannin sorghum. The frequency of attribute nice taste was similar for samples BRS330, BRS373, BRS501 and CMSS005 corroborating the ANOVA test for GSA.

Table 7. Attributes frequencies from CATA question.

Attributes	BR305	BRS330	BRS373	BRS501	CMSS005	SC319
Characteristic flavor	22^{a}	36^{b}	34^{b}	36^{b}	45^{a}	28^{c}
Sweet taste	7^{a}	10^{a}	7^{a}	11^{a}	9^{a}	6^{a}
Bad flavor	28^{a}	13^{b}	13^{b}	10^{b}	9^{b}	25^{a}
Snacks taste	10^{c}	26^{a}	20^{b}	27^{a}	19^{b}	13^{c}
Without salt	87^{a}	86^{a}	83^{a}	84^{a}	83^{a}	85^{a}
Without seasoning	85^{a}	85^{a}	82^{a}	81^{a}	82^{a}	84^{a}
Nice taste	10^{b}	21^{a}	20^{a}	20^{a}	25^{a}	10^{b}
Bitter taste	19^{a}	12^{b}	15^{b}	2^{c}	11^{b}	22^{a}
Burnt flavor	20^{a}	10^{a}	9^{a}	10^{a}	9^{a}	16^{a}
Soft texture	32^{a}	27^{a}	25^{a}	23^{a}	30^{a}	22^{a}
Crunchy	60^{b}	77^{a}	77^{a}	79^{a}	74^{a}	70^{a}
Sticky on teeth	60^{a}	50^{a}	53^{a}	57^{a}	58^{a}	60^{a}
Little crunchy	20^{a}	6^{c}	9^{b}	5^{c}	10^{b}	12^{b}
Hard	6^{a}	3^{a}	4^{a}	4^{a}	3^{a}	3^{a}
Sandy	13^{a}	21^{a}	15^{a}	19^{a}	18^{a}	21^{a}
Little expanded	37^{a}	12^{b}	12^{b}	8^{b}	9^{b}	23^{a}
Expanded	15^{b}	36^{a}	32^{a}	41^{a}	38^{a}	22^{b}
Dark points	19^{a}	24^{a}	18^{a}	12^{a}	14^{a}	17^{a}
Dark color	75^{a}	48^{b}	53^{b}	0^{c}	1^{c}	77^{a}
Light color	0	2^{b}	3^{b}	73^{a}	70^{a}	2^{b}
Bright brown color	16^{b}	41^{a}	37^{a}	22^{b}	34^{a}	18^{b}
Characteristic flavor	13^{a}	18^{a}	18^{a}	16^{a}	16^{a}	14^{a}
Without flavor	57^{a}	50^{a}	54^{a}	48^{a}	57^{a}	59^{a}
Snack flavor	2^{a}	9^{a}	5^{a}	10^{a}	6^{a}	5^{a}
Sweet flavor	2^{a}	5^{a}	3^{a}	8^{a}	4^{a}	2^{a}

Sig. significance for Cochran Q test, * indicate the attribute presented statistical differences among expanded from different sorghum genotypes ($p<0.05$). Different letters in the same row indicate differences among treatments ($p<0.05$) by chi squart for Q cochran test.

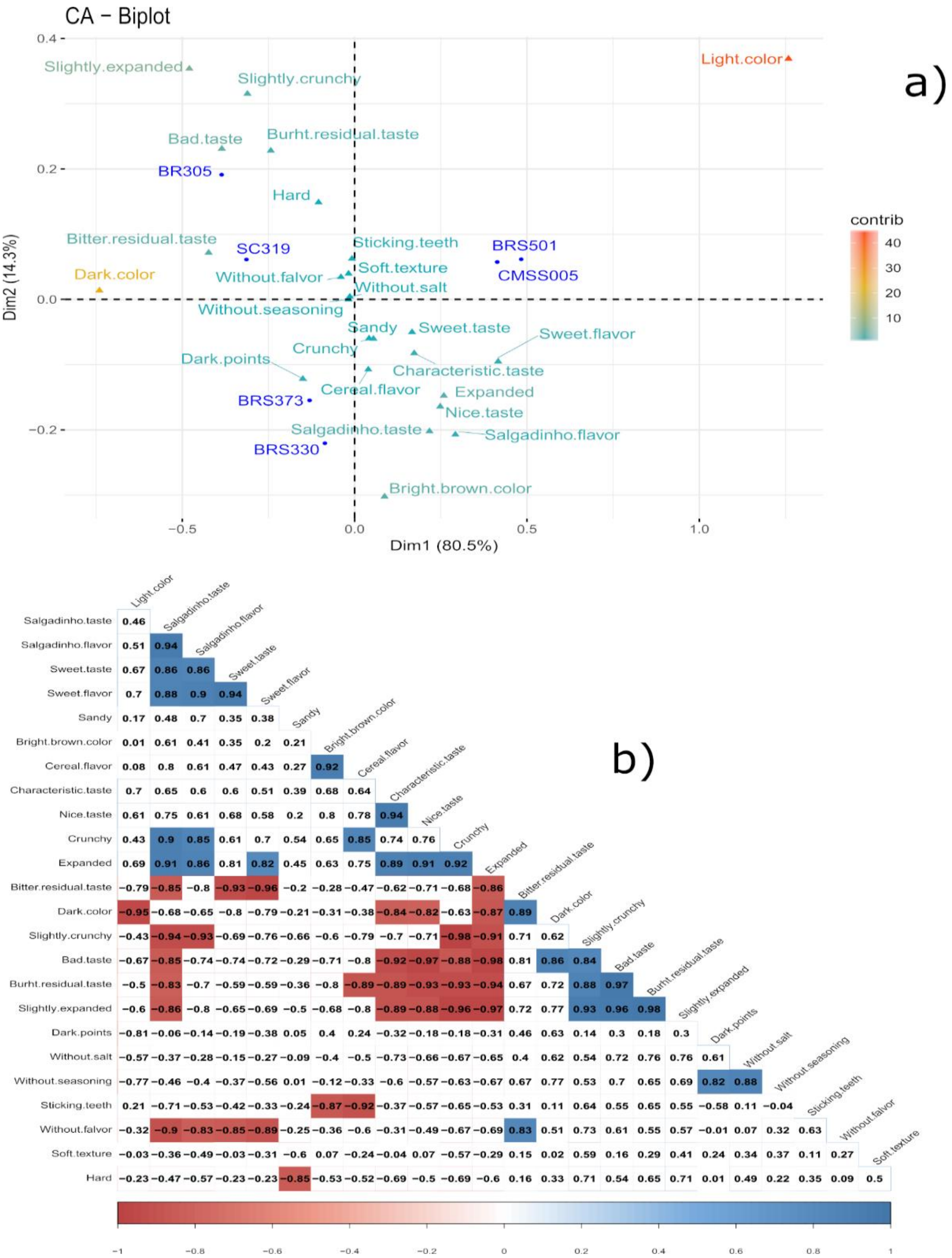


Figure 6. Correspondence analysis on data from CATA questions (a), and correlogram (b) for the sensory attributes, numbers (r values) without background have no significant Pearson correlation (p>0.05), numbers with red or blue background in Table body indicate negative and positive significant correlation (p<0.05) respectively.

The Pearson coefficient correlation (Figure 6b) was calculated to understand relations between attributes, e.g. there was a very high and positive correlation between the terms snack taste vs. snack flavor and sweet taste and vs. sweet flavor. As was expected there were negative correlation between opposite characteristics such us dark color vs. light color, bas taste vs. snack taste, etc.

The multiple factor analysis (MFA with 81.29% of the variance explained by the two first components) was carried out to obtain a global experiment explanation, thus, observing Figures 7a and b with could note that the samples BRS373 and BRS330 were nearest to cereal flavor, definitively buying, cereal crispness, samples CMSS005 and BRS501 were mores related to SEI, sweet taste, light color nice taste, and samples SC319 and BR305 were closed to antioxidant properties and bat attributes, on the other hand in individual factor map (Figure 7b) it is possible to observe that BRS373 and BRS330 had similar antioxidant characteristics and a little bit GSA and buying intention, but different extrusion responses and CATA results, finally SC319 and BR305 far from the other samples with particular responses.

The hierarchical clustering from principal components of the MFA confirm the previous clustering samples in Figure 4d, thus it could be possible to order the six sorghum samples into three groups for the reasons explained above paragraphs.

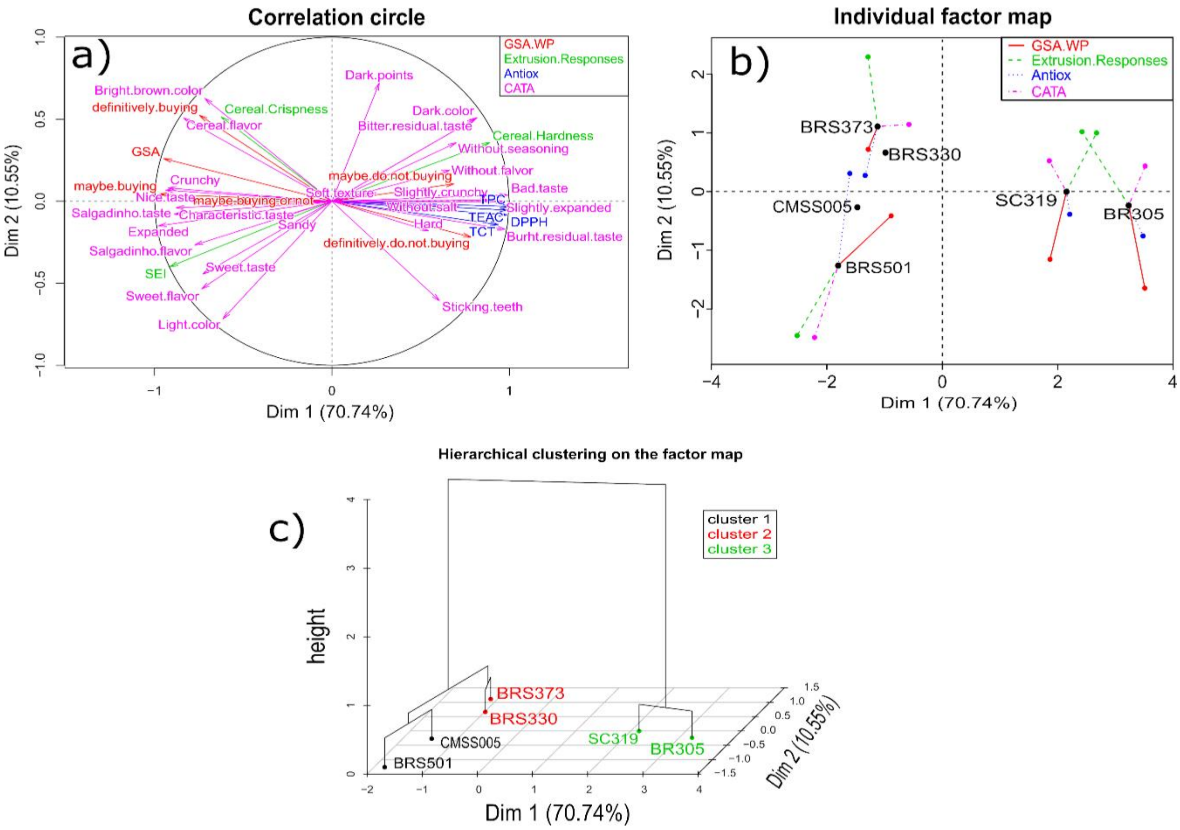


Figure 7. Multiple factor analysis using general sensory acceptance, buying intention, extrusion responses antioxidant properties and CATA test as factors, a) Correlation circle the responses variables, b) Individual factor map, c) Hierarchical cluster from principal components of the Multiple factor analysis.

CONCLUSIONS

It was obtained three sorghum genotypes groups based on their shape, chemical composition, antioxidant properties, extrusion and sensory responses. The groups was obtained from six sorghum genotypes. The first groups was performed by tannin sorghum genotypes (BR305 and SC319), those had better functional properties that include total condense tannin, total phenolic compounds, antioxidant properties, in contras they had the less symmetric shape (sphericity). Additionally, it would be recommend the use of the Imagej software that allows a good analysis precision for free. Extrusion and sensory responses, on the opposite side is the groups formed by white sorghum genotypes (CMSS005 and BRS501), and close to the white sorghum genotypes were BRS373 and BRS330, with acceptable extrusion and sensory characteristic. The consumer acceptance could be improve with some seasoning like sugar and salt. Finally, it would be advisable to mix tanning sorghum with red nom tannin sorghum or even with sorghum genotypes in order to optimizing the extrusion sensory and functional properties. Thus, it would be advisable to used two sorghum genotypes (BR305 and BRS373 with tannin and non-tannin content) for further studies in order to optimized functional properties and sensorial acceptance.

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Optimization of antioxidant capacity and sensory analisys of whole grain breakfast cereals using tannin and non tannin sorghum genotypes

Resumo

Farinhas de grão inteiro de dois genotipos de sorgo (com e sem tanino, BR305 e BRS373 respetivamente) foram misturadas com proporções vaiando de 0 a 90%, também foram adicionadas de açúcar (0 a 10%) e processadas em extrusora de parafuso duplo para se obter cereal matinal com formato de extrudados expandidos. As respostas: índices de absorção e solubilidade em água (WAI e WSI), índice de expansão radial (SEI), textura instrumental, tempo de tigela, aceitabilidade sensorial e questionário CATA, assim como analises de capacidade antioxidante foram utilizadas para estudar a melhor mistura e o teor de açúcar para alcançar alta capacidade antioxidante e sensorial. A mistura com maior conteúdo 90%de sorgo com tanino (BR305) apresentou os maiores teores de compostos fenólicos totais e capacidade antioxidante, também apresentou baixa expansão radial, alta solubilidade e menor absorção de água assim como menores valores de tempo de tigela, bem como a menor aceitação sensorial, enquanto misturas ricas de sorgo sem tanino (sorgo BRS373) tiveram melhor resultados opostos. A mistura otimizada consistiu de 45% de sorgo com tanino, 45% de sorgo sem tanino e 10% de açúcar, que obteve uma média de 6 pontos de aceitação sensorial numa escala de 9 pontos. Além disso, a ausência de uma boa metodologia para a determinação de tempo de tigela foi detectado, sendo proposta uma cinética de deterioração da dureza instrumental, como método para determinar o tempo médio de tigela, sendo o modelo probabilístico de Weibull, aquele que apresentou o melhor ajuste.

Palavras-chave: Cozimento por extrusão, análise fatorial múltipla, tempo médio de tigela, modelo probabilístico de Weibull, CATA.

Abstract

Tannin and non-tannin whole grain sorghum flours were mixed (0 to 90%) added of varied content of sugar (0 to 10%) and processed in a twin screw extruder to obtain breakfast cereal with format of ball shape puffed extrudates. Extrusion responses (water and solubility indices (WAI and WSI), sectional expansion index (SEI)), instrumental texture (crispness, hardness and bowl life), sensory (acceptability and CATA question) and antioxidant capacity analyses were used to identify the best mixture to achieve high sensory and antioxidant capacity. Rich blend of tannin sorghum (with 90% of BR305) presented the highest levels of total phenolic compounds and antioxidant capacity, also it presented low SEI, high WSI and low bowl life, as well as the lowest sensory acceptance, whereas rich blends of non tannin sorghum presented the opposite responses. Optimized blend consisted of 45% of tannin sorghum, 45% non-tannin sorghum and 10% of sugar that had a mean sensory acceptance of 6 from 9 points sensory scale. In addition, a lack a good bowl life determination was found to be relevant to measure this property, thus it was proposed a method of measuring half bowl life by using Weibull probabilistic model that should be expressed as function of time.

Keywords: Extrusion cooking, multiple factorial analyses, half bowl life, Weibull probabilistic model, CATA.

INTRODUCTION

Sorghum is a promissory cereal for producing whole grain healthy products due to its large amount of phenolic compounds that include flavonoids, phenolic acids, tannin and antocianins as well as a source of dietary fiber (CHÁVEZ et al., 2017; LOPES et al., 2018; QUEIROZ et al., 2018) and abundant in minerals (RANI et al., 2016). Depending on the sorghum cultivar, it is also a source of carotenoids and vitamin E (VALLABHANENI et al., 2010; CARDOSO, PINHEIRO, DA SILVA, et al., 2015; ANUNCIAÇÃO et al., 2017), resistant starch (CHARALAMPOPOULOS et al., 2002), among other functional properties. The diversity and high levels of phytochemicals place sorghum as a valuable crop for promoting health as other fruits and vegeTables (AWIKA; ROONEY, 2004), it is a gluten free grain that would suit to all people including celiac and those with any gluten-related disorders (DE MESA-STONESTREET et al., 2010; RATNAVATHI; PATIL, 2013; JNAWALI et al., 2016; WITCZAK et al., 2016).

Studies have reported that consumption of whole grains like sorghum, reduces mortality from different illness such as cardiovascular, degenerative, atherosclerosis, obesity, diabetes, dyslipidemia, and cancer, among other diseases, possibly related to its antioxidant properties (AWIKA; ROONEY, 2004; SALAWU et al., 2014; LLOPART; DRAGO, 2016). In addition, products with tannin-sorghum could provide lower calories products comparing with non-tannin-base products (AWIKA et al., 2003).

In some countries sorghum have been explored as ingredient for formulating ready-to-eat products using different technologies, including extrusion cooking process (DLAMINI et al., 2007; ADARKWAH-YIADOM; DUODU, 2017). According to Brennan et al. (2011), extrusion of whole grain is advantageous to develop products with high amount of phenolic compounds resulting in products with low sensory acceptance. Nevertheless, some phenolic compounds could compromise the palatability due to their strong bitterness and astringency resulting in low sensory acceptance (LESSCHAEVE; NOBLE, 2005), therefore bitterness and astringency could be the main cause of undesired use of tannin sorghum genotypes (AWIKA; ROONEY, 2004; CARDOSO, PINHEIRO, DE CARVALHO, et al., 2015; QUEIROZ et al., 2018).

In the previous chapter, where six sorghum genotypes (including tannin and non-tannin sorghum) were processed by extrusion, it was found that tannin-sorghum genotypes presented, as expected, the highest antioxidant properties. As mentioned above, tannin-sorghum presented poor sensory acceptance due its bitter and astringent taste, as well as low expansion of undesirable appearance. On the contrary, non-tannin sorghum shows good sensory responses, but low antioxidant capacity, which in turn is not a desirable property considered in healthy products. The main objective of the current study was to optimize antioxidant capacity and sensory responses of puffed extrudates using blends of tannin and non-tannin sorghum genotypes (BR305 and BRS373 respectively) and also to study the sugar effect on sensory acceptability and antioxidant capacity.

MATERIALS AND METHODS

Plant materials

Two sorghum genotypes were provided from Embrapa (Brazilian Agricultural Research Corporation) Maize and Sorghum (Sete Lagoas, Brazil) located at 19° 28´ south latitude and 44° 15´08´´ and 32 m of altitude. The studied sorghum genotypes were BR305 (tannin) and BRS373 (non-tannin). The sorghum was planted in the experimental field in May 2014, and the harvesting took place in May 2015. The kernels were cleaned and stored at 8 ± 2 °C until further analyses.

Extrusion conditions

Sorghum were grounded in a hammer-mill (HM) LM3100 (Perten Instruments AB, Huddinge, Sweden) fitted with a 1.0 mm sieve aperture flours, before the extrusion, each treatment was preparing mixing both sorghum genotypes (BR305 and BRS373) and sugar, the total weighed for batch was 2.5 kg including 1% of chocolate flavor (the amount of each ingredient is detailed in Table 1), then, the moisture was satirized at 14g/100g, rested for overnight at 8°C, to ensure a uniform hydration.

For extrusion it was used an extrusion machine of Clextral Evolum HT25 corotating, intermeshing twin-screw extruder (Clextral Inc., Firminy, France) with screw diameter of 25 mm, the proportion for length and diameter ratio was 40:1 and ten temperature zones configured at 25, 40, 60, 90, 110, 110 110, 120, 120 and 120 °C. With screw speed of 500 rpm and the feed rate was 10 kg/h, the die had four holes of 3.88 mm, following by a cutting four pallet sniff adjusted at a speed of 900 rpm. The product was collected after the process stabilization, drying at 60 °C for 4h, cooled and stored at 8 °C for further analysis.

Experimental design

An experiment based on constrained mixture simplex-centroid design (Table 1) was used because it is not possible to produce snack with e.g. 100% of sugar. The restrictions for each component were: sorghum BR305 (0-90%), sorghum BRS373 (0-90%) and sugar (0-10%). Results were adjusted to the following polynomial model:

$$Y = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{123} X_1 X_2 X_3 \quad (1)$$

Where: X1, X2 and X3 are the concentrations of sorghum BR305, sorghum BRS373 and sugar, βn are the regression coefficients, Y are the responses variables (Sectional expansion index, Bulk density, Water absorption index, water solubility index, Hardness and bowl life among others).

The desirably function was performed to obtained optimized values of sorghum BR305, sorghum BRS373 and sugar in order to maximized the more representative responses.

Table 1. Proportions of sorghum genotypes and sugar on constrained mixture simplex-centroid.

Treatment	Tannin sorghum BR305	Non-tannin sorghum BR373	Sugar
D1	0.900	0.100	0.00
D2	0.900	0.000	0.10
D3	0.000	0.900	0.10
D4	0.100	0.900	0.00
D5	0.500	0.500	0.00
D6	0.900	0.050	0.05
D7	0.050	0.900	0.05
D8	0.450	0.450	0.10
D9	0.475	0.475	0.05
D10	0.475	0.475	0.05

Extrusion transverse circularity

The transverse circularity of the extrudates (ETCxy) was measurement by digital image techniques using 72 images for each treatment. The 2D image was taken from the (transverse section) in XY plane (were X is the bigger axes of the extruded and Y is the orthogonal axes in the picture). The pictures were taking using a digital camera (Nikon, D7200 N1406, Nikon corporation, Thailand, equipped with an optical macro Sigma 105 mm 1:2.8 DG MACRO HSM), camera settings were Focal distance: 10 cm; Digital Zoom: 1; Flash: off; Iso velocity: 400-ISO; Operation mode: Manual; Aperture Average: f/13, Exposure Tv: 1/15 s; Macro: On. A free analyzer image software call ImageJ (http://imagej.nih.gov/ij/) was used to obtained the ETCxy.

Sectional expansion index (SEI) and bulk density (BD)

The SEI was calculated using the equation proposed by Alvarez-Martinez et al. (1988), with some modifications, due the shape of almost all treatments was closed to a sphere and was necessary to make a thin cut (~4mm) in the most regular part to obtain a flattened cylinder (n=16 per treatment), since the cut piece were small and fragile it was no possible to measurement then with a vernier, instead, it was used pictures to analyzed in the free software imagej (available in http://imagej.nih.gov/ij/). Two pictures were taken for each treatment. The first picture was taken in plane XY to obtain the length (L: mean of 5 measurements per each piece). The other one was taken in the plane XZ (cylindrical) of the pieces to obtained the cylindrical area (A) and calculate the mean of the diameter (D) and SEI with equations 2 and 3 respectively. The pictures were taken with a digital camera (Nikon, D7200 N1406, Nikon corporation, Thailand, equipped with an optical macro Sigma 105 mm 1:2.8 DG MACRO HSM) with similar configurations than in extrusion shape characterization.

$$D = \sqrt{\frac{A*4}{\pi}} \quad (2)$$

$$SEI = \left(D / D_o\right)^2 \quad (3)$$

$$BD = 4.m / \pi.L.D^2 \quad (4)$$

Where: A is the cylindrical area (mm^2); D is the medium diameter of the extrudates (mm); D_o is the die diameter (mm); SEI is sectional expansion index; m is the weight (g); L is the cylinder length (mm) and BD is the bulk density (g/cm^3).

Water absorption and water solubility indexes

The extrudates were ground using a mill LM3100 (Perten Instruments AB, Huddinge, Sweden) fitted with a 1.0 mm sieve aperture flours, then was sieved and the retained fraction between 212 and 106 µm was used. Water absorption index (WAI) and water solubility index (WSI) were using the methodology described by Anderson et al. (1969). Sample (1 g) gram was mix with distillated water (10 mL), shaked smoothly for 30 min at 25 °C in a Dubnoff water bath NT 232 (Novatecnica, Piracicaba, SP, Brazil) and centrifuged (3000g/15min) using a centrifuge Universal 320R (Hettich, Tuttingen, Germany). The supernatant was drying in an air circulating oven (WTB Binder, Tuttlinger, Germany) at 105 °C for 4 h, this data is used as the weight of the water soluble matter, and the remaining gel formed in the test tube was also weighting. WSI and WAI was calculated by the following equations:

$$WSI = \left(Water\ soluble\ matter\ \left(g\right)\right) x100 / \left(Dry\ sample\ \left(g\right)\right) \quad (5)$$

$$WAI = \left(Formed\ gel\right) / \left(Dry\ sample\ \left(g\right)\right) \quad (6)$$

Extraction from the extrudates

The sample extraction was performed twice to obtain the maximum hydrophilic and hydrophobic compounds. One gram of the whole milling sample was mixture with 5 ml of methanol (50%), into a 15 mL teste tube, homogenized in a vortex (Genie 2 Scientific Industries, Bohemia, NY, USA), resting by 30 min, posteriorly was centrigugated at 9000*g* for 15 min, filtered through a rapid past paper. The second extraction was done using the solid residue by adding 5 mL of acetone (70%) and following the same steps. The sobrenadants were joined in other 15 test tube and the volume was complete until 10 mL with milli-Q water. The extraction were stored at -18°C for further analyses.

Total phenolic compounds (TPC)

TPC was quantified according to Ludwig et al. (2012). It was used Gallic acid as a standard (concentration ranged from 0.03 to 1.5 mg/mL). The absorbance was read at 760 nm using a spectrophotometer UV-1800 (Shimadzu Corporation, Kyoto, Japan). TPC were expressed as mg of Gallic acid equivalents (mg GAE)/g.

Antioxidant determinations

The antioxidant capacity were determined using synthetic free radicals (DPPH and ABTS) methods described Brand-Williams et al. (1995) by RE et al. (1999) and the absorbance of the reaction after 30 min was red at 734 nm and 515 nm respectively in a spectrophotometer UV-1800 (Shimadzu Corporation, Kyoto, Japan). It was used Trolox curves (for each assay ABTS and DPPH) as standards. Three replicates were made and the results were expressed in μmol Trolox equivalent/gram of sample (μmol TE/g) antioxidant capacity (TEAC) and were calculated dividing the gradient of the inhibition percentage vs. sample concentration by the gradient of the plot of the inhibition percentage (Equation 3) vs. Trolox concentration for each assay. Ferric-reducing antioxidant power (FRAP) assay was performed based on the procedure described by Thaipong et al. (2006) with some modifications. The absorbance was taken at 595 nm. The standard curve was linear between 100 and 1000 μM of Trolox equivalent. Results were expressed in μM of Trolox equivalent per gram of dry weight (μM TE g-1).

Texture analysis in the extrudates

Previously, the extrudates were drying (60 °C x 4 h). The texture was measurement (n=30) on a Texture Analyser TA-XT Plus (STable Micro Systems, Surrey, England) running Exponent software 6.1.11.0 (STable Micro Systems, Surrey, England). The equipment was armed with 50 kg load cell, with and adapter cylinder of 41.6 mm diameter and 76 mm high, this cylinder had 8 holes of 3mm of diameter (symmetrically distribuited at the base of the wall to drain the milk in the future bowl life test) and a back extrusion rig (probe) 41.5 mm diameter. Approximately 2.43 ± 0.35 g was placed inside the cylinder, to form two layers. The test was configuration in mode "measure force" in with probe distance of 8 mm, pre-test speed of 10 mm/s, test speed of 1 mm/s and post-test speed of 10 mm/s. The snack hardness was consider as the peak force (N) (BOUVIER et al., 1997).

Bowl-life assay

It was used the methodology described by (OLIVEIRA et al., 2017) with modifications. The snacks (geometry spheres) were soaked in semi-skimmed milk (2.48 ± 0.47 g/10 mL) (1:4 v/v) at 10°C for different times (in order to obtain a hardness kinetics degradation curve and calculated the $t_{(½)}$:middle bowl-life or the middle time to get half initial hardness, this is a new measurement proposed in this study for real quantification of bowl-life in which the result is expressed in time units as its synonym expression "shelf-life"), samples were drained for 15s before the measurements. The test configuration was for the same for the texture snack assay, using the same cylinder and probe, ten measurements were performed for each time.

The mean values of hardness at each immersion time were fitted to determinate the middle bowl life with. The deterioration on the hardness (C_t) was calculated by integrating the fundamental general kinetic equation (equation 7). Where, *k* is the rate constant and *n* is the reaction order. The general equation was integrated to obtain the zero, first and second order kinetics (equations 8, 9 and 10) (VAN BOEKEL, 1996).

$$-\int_{C_0}^{C} \frac{dC}{C^n} = \int_0^t k\,dt \qquad 7$$

$$C_t = C_0 - k\,t \qquad 8$$

$$C_t = C_0 * \exp(-k\,t) \qquad 9$$

$$\frac{1}{C_t} = \frac{1}{C_0} + k\,t \qquad 10$$

Where, C is hardness in the time t, n is the reaction order, t is the time. C_0 is the initial texture.

The cereal texture changes soaking in a liquid was previously described as “a rapid nonequilibrium dual mass transfer process, which involves the concurrent uptake of moisture and the uptake or loss of soluble solids” by Machado et al. (1999), the authors conclude that the best fitted was obtained with the probabilistic. Thus the Weibull probabilistic model was also used to fit the hardness changes (equation 8), the equation was rearranged to model data in function of texture at any time (C_t) (equation 9).

$$\frac{C_t - C_0}{C_\infty - C_0} = 1 - e^{-\left(\frac{t}{\beta}\right)^{\alpha}} \qquad 11$$

$$C_t = C_\infty + \left(C_0 - C_\infty\right) e^{-\left(\frac{t}{\beta}\right)^{\alpha}} \qquad 12$$

Where, C_t is texture at time t, C_0 is texture at time zero, C_∞ is texture at infinity time, β is scale parameter (different of zero), and α is the shape parameter.

Sensory analysis

The sensory tests were performed with 95 consumers (28.7% 0 males and 71.3% females), which included graduate and post-graduate students, researches and employees that were recruited from Embrapa Food Technology. Ethical approval was provided by The Human Ethics Research Committee at Federal University of Minas Gerais, Brazil, approved this study (N° 03591312.0.0000.5149). Socioeconomic characteristics and income information were taken from participants.

Snacks were served (2-4 g) in a coded (three number) plastic cups of a capacity of 35 ml. Water was used to clean the mount between samples. Sensory acceptance was evaluated by using 9 point scale. Sensory attributes were evaluated using 30 characteristics in CATA question, these attributes were previously defined by 15 panelists. The data were collecting by used software Fizz (Biosystemes, França).

Data statistical analysis

It was used one-way ANOVA to determinate differences among the treatments, and Tukey multiple range test was apply where was needed. Multivariate statistical analysis was applied to better describe the phenomena. Principal component analysis (PCA) was running after data satirized to avoid the effect of the different magnitude order and units of the variables. PCA was applied to understand the correlation between variables and samples. Hierarchical Clustering on Principle Components (HCPC) was performed to form samples groups with similar characteristics. HCPC is a clustering technic making from the results of the PCA, the algorithm of the HCPC use Euclidian distances and Ward´s criterion on the principal components, then k-means clustering is apply to improve and consolidation the initial hierarchical clustering. Cochran's Q test was performed for to identify significant attributes between samples on the each CATA attribute, finally Correspondence Analysis (CA) on attribute frequency from CATA question to obtain maps representing the attributes that characterized each sample. Multiple factor analysis was performed for make a global analysis, which could include quantitative and qualitative responses variables, in this way, physico-chemical, antioxidant capacity, sensory acceptance and CATA question could be analyzed at the same time.

The most representative responses variables were chosen for mixture design, analysis and surface generation, was used. Linear, quadratic and special cubic models were tested. For each response, the model with the highest adjusted R^2 value. All statistical analysis were carried out at a significance of 5% ($\alpha = 0.05$). Statistical analyses were performed using Statistica 10 software (StatSoft, Tulsa, EUA) and the software R for statistical computing, version 3.2.4 (CORE_TEAM, 2017) and the FactoMineR package version 1.32.

RESULTS AND DISCUSSIONS

Mathematical model for mixture constrained design

The mathematical model for mixtures responses is presented Table 2, all variables presented linear models with the exemption of half bowl life. Regarding to interpretation of the models, all positive coefficients indicate a direct effect in the responses, on the other hand the negative coefficients means contrary effect in response variables. The p_value for the model was significant ($p<0.05$) for almost all variables, whereas the lack of fit test that measures the accuracy of the model result significant for most variables, and the R^2ajust values ranged from 0.52 to 0.94. From these results it is possible to affirm that the model for GSA is sufficiently accurate for predicting the consumer responses, additionally, the models for the other variables could inadequate tendencies.

Table 2. Mathematical model for mixture constrained design of the extrudates characteristics

Mathematical model for response variables in mixture design	Model	Model significance (p Value)	Lack off fit (p Value)	R^2	R^2ajust
ETCxy = $0.6504X_1 + 0.7338X_2+2.0065X_3$.	Linear	**0.0092**	**0.0302**	0.738	0.666
WAI = $3.5324X_1 + 3.8354X_2 + 7.1174X_3$	Linear	**0.0318**	0.0896	0.6265	0.5198
WSI = $34.0607X_1 +20.5726X_2 + 4.0523 X_3$	Linear	0.0264	**0.0113**	0.6458	0.5446
TPC = $4.5304X_1 + 1.0074X_2 - 8.6847X_3$	Linear	**0.0071**	0.072	0.7572	0.6878
DPPH = $24.3734 X_1 + 5.4429X_1 - 48.0356 X_3$	Linear	**0.0198**	**0.0246**	0.6737	0.5805
FRAP = $1.4771X_1 + 0.3570X_2 - 2.9972 X_3$	Linear	**0.0107**	**0.0386**	0.7264	0.6482
Hardness = $93.5653X_1 + 102.4548X_2 - 453.6274 X_3$	Linear	**0.0099**	**0.0017**	0.7327	0.6564
Half bowl life T(1/2) = $12.9073X_1 + 108.7864X_2 + 599.8580X_3 -12533.451X_1X_3 + 22650.1802X_1X_2X_3 +15433.35015X_1X_3 (X_1-X_3)$	Special cubic	**0.0098**	**0.000**	0.9424	0.8704
GSA = $3.5699X_1 + 4.5228X_2 + 21.4014X_3$	Linear	**0.000**	0.468	0.9565	0.9441

Were, X_1, X_2 and X_3 are the proportion of the BR305, BRS373 and Sugar respectively, ETCxy is extrudates transverse circularity, WAI and WSI are the water adsorption and solubility respectively, TPC is the total phenolic compounds (mg GAE/g), DPPH and FRAP are the antioxidant capacity in from of the DPPH and FRAP respectively both expressed as is µmol trolox/g, GSA is the general sensory acceptance, P values and the Lack of fit were consider significant at 5%.

Shape and expanded extrusion responses

The extruded transverse circularity (ETCxy) were availed by image analyses (Table 3), in which the "X" axes represented the biggest axes and "Y" represent the axes in which the radial expansion occurs. ETCxy values is a new proposed for rapid and cheap measurement method. The values of ETCxy were significant influenced ($p<0.05$) by sorghum BR305, BRS373 and Sugar concentrations (Figure 1a). The treatment D1 (BR305/BRS373/Sugar of 0.9/0.0/0.1) had the lowest ETCxy value with 0.590 ± 0.06 (Table 3 and Figure 1a), on the other hand the treatment without BR305 (D3 with 0.0/0.9/0.1 for BR305/BRS373/Sugar) presented the biggest value (0.831 ± 0.028). On the other hand, BRS373 and sugar contend favored significant ($p<0.05$) the ETCxy, sugar proportion presented the biggest effect in the ETXxy as could be observed in its mathematical model in Table 2. By the results, is evident that the amount of tannin sorghum BR305 influenced negatively in ETCxy, this could be attributed to the highest values TPC (Table 2) in these genotype, PCA and the correlogram (Figures 5 a, b and c) corroborated the negative correlation between TPC and TPC with r=-0.78 which according to Mukaka (2012), these Pearson correlation value correspond to a high negative correlation . Contrary that is usually that the BD has direct correlation with expansion (BRENNAN et al., 2013), in these work BD was not related to SEI (Table 3), BD ranged from 0.051 ± 0.013 to treatment D1 and 0.118 ± 0.009 g/cm^3 for D7 (0.05/0.90/0.05 for BR305/BRS373/sugar respectively), in general the treatments with more BR305 sorghum presented the lower values, and treatment with sugar had higher values.

Table 3. Extruded transverse circularity, bulk density and sectional expansion index

Treatment	ETCxy	BD (g/cm3)	SEI
D1	0.590 ± 0.060^{g}	0.051 ± 0.013^{f}	6.931 ± 0.778^{d}
D2	0.765 ± 0.046^{d}	0.071 ± 0.013^{def}	8.642 ± 0.692^{b}
D3	0.831 ± 0.028^{a}	0.054 ± 0.008^{ef}	10.776 ± 0.720^{a}
D4	0.724 ± 0.030^{e}	0.073 ± 0.007^{def}	7.610 ± 0.452^{cd}
D5	0.700 ± 0.044^{f}	0.084 ± 0.020^{cd}	5.928 ± 0.314^{e}
D6	0.778 ± 0.035^{cd}	0.081 ± 0.013^{cd}	8.231 ± 0.126^{bc}
D7	0.795 ± 0.032^{bc}	0.118 ± 0.009^{a}	6.952 ± 0.391^{d}
D8	0.811 ± 0.029^{b}	0.106 ± 0.020^{ab}	7.037 ± 0.437^{d}
D9	0.792 ± 0.03^{b0c}	0.086 ± 0.018^{bcd}	6.865 ± 0.364^{d}
D10	0.794 ± 0.023^{bc}	0.096 ± 0.016^{bc}	6.892 ± 0.541^{d}

Values represent the mean ± SD, ETCxy is the extruded transverse circularity (n=72), BD is bulk density and SEI is sectional expansion index (n=16 for both), the same later within a column means no statisitical differences by tukey test with a significant of 5%

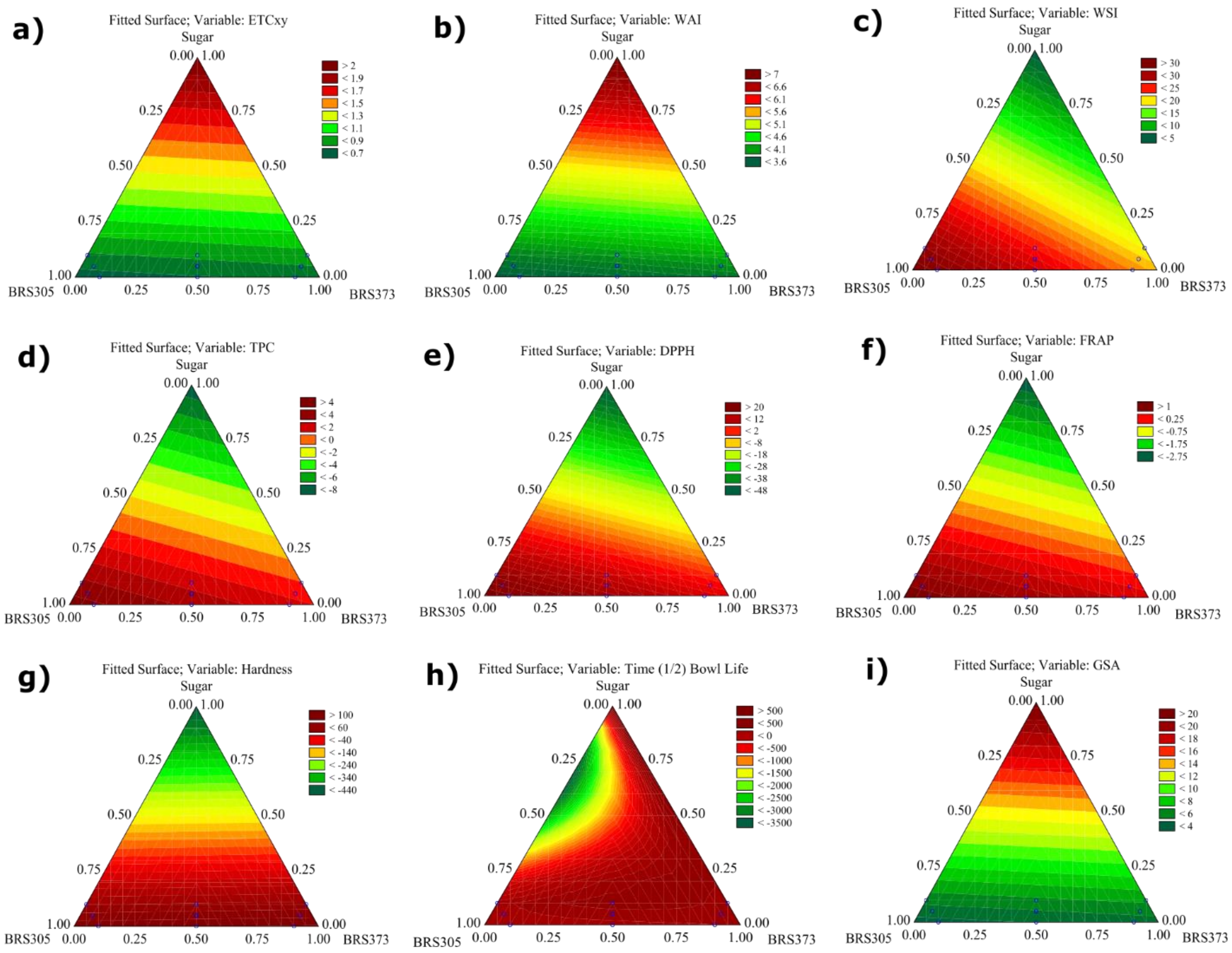

Figure 1. Contour graph (right) for extruded transverse circularity (a), water adsorption and solubility indexes (b and c respectively), total phenolic compound (d), DPPH (e), FRAP (f), hardness (g), half bowl life (h) and general sensory acceptance (i) as function of BR305, BRS373 and Sugar concentrations.

Regarding to SEI, presented a similar behavior of ETCxy thus, the sugar addition in diminish of tannin sorghum had a positive ($p<0.05$) effect with the SEI (Table 3), this could be explain due by the possible tannin-sugar complexation and in this way the starch could be available for conversion. Dlamini et al. (2007), mention that the processing reduce the tannin contend by the interaction of tannin with proteins and carbohydrates including sugar. On the other hand, SEI decreased when the sugar amount were in competition with non-tannin sorghum, in this case sugar could act as a diluent for the starch as was previously reported by Carvalho e Mitchell (2000).

Hydration and texture properties

In Table 4, WAI values ranged from 3.49 ± 0.23 to 4.16 ± 0.40. WAI is attributed to the starch dispersion in water excess, the dispersion is direct related to the starch damage by the gelatinization and fragmentation induced for extrusion process (LOHANI; K., 2017), in other words, WAI is related to the availableness hydrophilic groups (CHÁVEZ et al., 2017). The sorghum BR305, BRS373 and sugar proportions influenced significantly (p<0.05) in the WAI, it is possible to observe by the coefficients of the mathematical model in Table 2, that, sugar has about the double effect comparing with both tannin and non-tannin sorghum, sorghum BRS373 presented major effect than the BR305, as was mention, this could be due for major phytochemicals compounds and high fiber contend in sorghum BR305, which may difficult the melted during extrusion (VARGAS-SOLÓRZANO et al., 2014).

Table 4. Extruded properties of mixtures (tannin and no tannin sorghum genotypes and sugar)

Treatments	WAI	WSI	Hardness (N)	Cripsness (Peack numbers)
D1	3.49 ± 0.23[c]	36.33 ± 1.82[a]	66.68 ± 9.22[cd]	55.50 ± 19.23[bc]
D2	3.87 ± 0.06[abc]	34.25 ± 1.24[ab]	35.56 ± 9.79[ef]	58.80 ± 6.16[bc]
D3	4.07 ± 0.06[ab]	23.01 ± 0.54[cd]	30.98 ± 3.35[f]	77.50 ± 12.70[ab]
D4	3.89 ± 0.06[abc]	25.42 ± 0.52[bcd]	100.02 ± 6.00[b]	73.25 ± 9.55[ab]
D5	3.61 ± 0.05[bc]	25.87 ± 0.25[bcd]	117.70 ± 11.96[a]	57.33 ± 7.09[bc]
D6	3.98 ± 0.07[ab]	31.88 ± 0.14[abc]	74.70 ± 7.08[cd]	83.83 ± 9.71[a]
D7	4.16 ± 0.40[a]	19.58 ± 1.94[d]	70.89 ± 5.03[cd]	84.00 ± 5.12[a]
D8	4.07 ± 0.21[ab]	23.38 ± 10.07[cd]	52.38 ± 3.76[de]	48.33 ± 11.37[c]
D9	3.73 ± 0.06[abc]	20.86 ± 0.80[d]	77.67 ± 6.26[c]	46.33 ± 18.58[c]
D10	3.70 ± 0.01[abc]	20.95 ± 1.11[d]	77.72 ± 7.89[c]	46.00 ± 5.16[c]

Mean ± SD, WAI and WSI are the water adsorption and solubility indexes respectively (n=4), hardness and crispness were measurement with 15 replicates, different letters within the same column means significant differences among treatments (p<0.05), by multiple means comparison tukey test.

WSI is usually used as an indicator of the degree of molecular degradation (starch conversion), which represent the quantity of soluble polysaccharide released from the starch after extrusion (LOHANI e K., 2017), the higher value of WSI was presented for the treatment D1 (36.33±1.82), these was corroborated by the higher coefficient of the BR305 in the mathematical model (Table 2), the next greater significant independent variable was the sorghum BRS373 and finally sugar was the lowest influence in WSI. The WAI and WSI in the present work are in contrast by the reported for Mkandawire et al. (2015), the author misunderstand the previous report of VARGAS-SOLÓRZANO et al. (2014), due the last author found statistical differences in WAI and WSI for tannin and non-tannin sorghum.

Related to snack hardness, its values ranged from 30.98 ± 3.35 to 117.70 ± 11.96 N, the three independent variables influenced in snack hardness (p<0.05), also, it was observed by the mathematical model (Table 2), that sugar had a negative effect in hardness, additionally the effect of sugar was ~4,5 times than both tannin and non-tannin sorghum, generally the extrudates treatment with more sugar contend presented lower hardness values (Table 4 and Figure 1g), this could be explain because sugar increase in extrusion may cause slightly less starch damages as was reported by Carvalho; Mitchell (2000). Regarding to crispness, generally the biggest values of crispness were presented for treatments with greater amount of non-tannin sorghum (BRS373), crispness is a measurement represent the number of peaks from the beginning until the end of the test, thus the bigger is the crispness value, the bigger the number of ruptures in the sample, according to Brennan et al. (2013), the crispness is related to the internal structure.

Antioxidant properties of the snack

Sorghum BR305, BRS373 and sugar had influence ($p<0.05$) in the antioxidant properties of the snacks (Table 5 and Figure 1d, 1e and 1f). Formulation with greater proportion of tannin sorghum presented the biggest values of antioxidant properties (Table 5), thus, treatment D1 (with 0.9/0.1/0.0 of BR305/BRS373/sugar) had values for TPC (mg GAE/g), DPPH, ABTS and FRAP (µmol trolox/g) of 5.87 ± 0.27, 33.31 ± 0.39, 40.53 ± 0.23 and 1.95 ± 0.09 respectively. By the mathematical model for mixture design, it is possible to observe shown that sugar had the stronger significant and negative effect (Table 5) on antioxidant properties, as was mention above, these could be due by the possible tannin-sugar complexation (DLAMINI et al., 2007), with the possible reduction of the available TPC and other phytochemicals, which in turns provide the antioxidant capacity for sorghum. Following these reasoning, in the opposite side, the treatment with lowest values of antioxidant properties was D3, these snack did not had tannin sorghum (BR305) in its formulation and the values for TPC (mg GAE/g), DPPH, and FRAP (µmol trolox/g) were 0.76 ± 0.04, 4.79 ± 0.07, 0.28 ± 0.01 respectively. Tannin sorghum genotypes were reported to have the biggest antioxidant capacity in comparison other whole grains (AWIKA et al., 2003; CHÁVEZ et al., 2017; QUEIROZ et al., 2018).

Table 5. Antioxidant properties of the extrudates for mixtures (tannin and no tannin sorghum genotypes and sugar)

Treatments	TPC (mg GAE/g)	DPPH (µmol trolox/g)	ABTS (µmol trolox/g)	FRAP (µmol trolox/g)
D1	5.87 ± 0.27[a]	33.31 ± 0.39[a]	40.53 ± 0.23[a]	1.95 ± 0.09[a]
D2	3.04 ± 0.12[b]	16.02 ± 0.57[c]	18.48 ± 0.53[b]	0.99 ± 0.05[b]
D3	0.76 ± 0.04[d]	4.79 ± 0.07[g]	10.50 ± 0.04[cd]	0.28 ± 0.01[e]
D4	1.04 ± 0.02[d]	6.71 ± 0.09[e]	8.07 ± 0.05[e]	0.40 ± 0.02[d]
D5	1.97 ± 0.15[c]	8.32 ± 0.06[d]	11.14 ± 0.07[c]	0.64 ± 0.03[c]
D6	2.85 ± 0.11[b]	17.21 ± 0.20[b]	19.17 ± 0.30[b]	0.98 ± 0.01[b]
D7	0.81 ± 0.11[d]	5.75 ± 0.01[f]	6.13 ± 0.41[f]	0.32 ± 0.01[de]
D8	1.64 ± 0.39[c]	8.65 ± 0.11[d]	9.85 ± 0.09[d]	0.55 ± 0.02[c]
D9	1.93 ± 0.10[c]	8.56 ± 0.06[d]	10.59 ± 0.08[cd]	0.57 ± 0.01[c]
D10	2.05 ± 0.08[c]	8.29 ± 0.13[d]	10.13 ± 0.14[d]	0.55 ± 0.01[c]

Mean ± SD, (n=3) TPC is the total phenolic compounds (mg GAE/g), DPPH and FRAP are the antioxidant capacity in from of the DPPH and FRAP respectively both expressed as is µmol trolox/g, different letters within the same column means significant differences among treatments ($p<0.05$), by multiple means comparison tukey test.

According with the Pearson correlation score proposed by Mukaka (2012), in these work, TPC had very high positive correlation with the antioxidant assays in these work (DPPH, ABTS and FRAP) with Pearson coefficient values of 0.98, 0.97 and 0.99 respectively (Figure 3c), the high antioxidant properties of phenolic compounds was largely demonstrated by other authors (AWIKA et al., 2003; CARDOSO, PINHEIRO, DE CARVALHO, et al., 2015; CHÁVEZ et al., 2017), also, TPC can be health beneficial against different diseases e.g. diabetes, obesity, dyslipidemia, oxidative stress, cancer, among others (AWIKA et al., 2003; CARDOSO, PINHEIRO, DE CARVALHO, et al., 2015; JAFARI et al., 2017).

Mathematical model for mixture constrained design

The mathematical model for mixtures responses is presented Table 6, all variables presented linear models with the exemption of half bowl life. Regarding to interpretation of the models, all positive coefficients indicate a direct effect in the responses, on the other hand the negative coefficients means contrary effect in response variables. The p_value for the model was significant ($p<0.05$) for almost all variables, whereas the lack of fit test that measures the accuracy of the model result significant for most variables, and the R^2ajust values ranged from 0.52 to 0.94. From these results it is possible to affirm that the model for GSA is sufficiently accurate for predicting the consumer responses, additionally, the models for the other variables could inadequate tendencies.

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WSI = $34.0607X_1 +20.5726X_2 + 4.0523 X_3$	Linear	0.0264	**0.0113**	0.6458	0.5446
TPC = $4.5304X_1 + 1.0074X_2 - 8.6847X_3$	Linear	**0.0071**	0.072	0.7572	0.6878
DPPH = $24.3734 X_1 + 5.4429X_1 - 48.0356 X_3$	Linear	**0.0198**	**0.0246**	0.6737	0.5805
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Hardness = $93.5653X_1 + 102.4548X_2 - 453.6274 X_3$	Linear	**0.0099**	**0.0017**	0.7327	0.6564
Half bowl life T(1/2) = $12.9073X_1 + 108.7864X_2 + 599.8580X_3 -12533.451X_1X_3 + 22650.1802X_1X_2X_3 +15433.35015X_1X_3 (X_1-X_3)$	Special cubic	**0.0098**	**0.000**	0.9424	0.8704
GSA = $3.5699X_1 + 4.5228X_2 + 21.4014X_3$	Linear	**0.000**	0.468	0.9565	0.9441

Were, X_1, X_2 and X_3 are the proportion of the BR305, BRS373 and Sugar respectively, ETCxy is extrudates transverse circularity, WAI and WSI are the water adsorption and solubility respectively, TPC is the total phenolic compounds (mg GAE/g), DPPH and FRAP are the antioxidant capacity in from of the DPPH and FRAP respectively both expressed as is µmol trolox/g, GSA is the general sensory acceptance, P values and the Lack of fit were consider significant at 5%.

Modeling the kinetic for bowl life and half bowl life ($T_{1/2}$) determination

The term bowl life remains shelf life, which is largely used to determinate the period of time a food product became unacceptable from (a) remain safe, (b) sensory, (c) comply any law or label declaration of nutrition data or safety (FU; LABUZA, 1993; HOUGH, 2010), the result of shelf life prediction are different kinetic models which allow to predict the period of time for rejection of the food (Table 7), in these way, the shelf life is always reported in time units (e.g. days, months, years). On the other hand, in available literature, bowl life has no clear definition, even dough the definition is apparent obviously, e.g Machado et al. (1999), refers to bowl life, as the loss of brittle texture by a cereal soaked in milk and became soggy, another definition was made by Gregson; lee (2002), who described bowl life as, the ability to maintain crips while the cereal is immersed in milk, note that both cases are not defining bowl life as a period of time. Recent studies are using bowl life test reporting the results in units different of the time, e.g. Zhang et al. (2014) reported bowl life in kg/s after 5 min the sample were soaking in water, on the other hand Oliveira et al. (2017) and Oliveira et al. (2018) reported bowl life as crispness (total number of measured force peaks) of the sample after 3 min soaking in milk, thus, is evident that exist a gape in the bowl life definition, measurement and result expression.

Table 7. Mathematical model for bowl life kinetic and half bowl life ($t_{1/2}$) estimation for snacks with sorghum BR305, BRS373 and sugar at different proportions, models used to fit the instrumental hardness as a function of time.

Treatment	Second order (n=2)					Weibull						
	k*100	P-value for K	R^2	P-value model	$T_{(1/2)}$ (s)	α	P-value for α	β	P-value for β	R^2	P-value model	$T_{(1/2)}$ (s)
D1	0.679 ± 0.045	<0.001	0.912	5.4E-06	22.1	0.560 ± 0.069	0.0030	10.79 ± 1.68	0.003045	0.998	4.59E-07	10.0
D2	0.401 ± 0.021	<0.001	0.943	1.24E-07	70.1	0.686 ± 0.059	8.349E-05	42.08 ± 2.79	2.3E-05	0.996	2.36E-08	46.8
D3	0.185 ± 0.010	<0.001	0.962	1.32E-07	174.7	0.806 ± 0.128	0.0014866	162.06 ± 18.97	0.000362	0.973	2.09E-06	171.1
D4	0.108 ± 0.000	<0.001	0.946	2.1E-07	92.5	0.723 ± 0.077	8.415E-05	152.71 ± 13.31	2.63E-05	0.986	1.18E-07	114.1
D5	0.105 ± 0.000	<0.001	0.985	2.2E-09	80.9	0.597 ± 0.059	5.401E-05	91.63 ± 8.61	4.07E-05	0.987	5.75E-08	67.2
D6	0.100 ± 0.000	<0.001	0.984	8.28E-10	133.9	0.592 ± 0.069	0.0001345	106.12 ± 11.81	0.000106	0.981	7.51E-08	96.2
D7	0.125 ± 0.000	<0.001	0.914	2.2E-07	112.8	0.746 ± 0.091	7.886E-05	178.27 ± 19.51	3.86E-05	0.971	4.2E-08	144.3
D8	0.104 ± 0.012	<0.001	0.848	1.94E-05	183.3	1.026 ± 0.157	0.001272	290.99 ± 24.38	7.28E-05	0.974	2.69E-06	267.5
D9	0.073 ± 0.000	<0.001	0.710	8.79E-08	176.0	0.556 ± 0.073	1.033E-05	244.90 ± 28.91	3.78E-06	0.928	6.6E-12	193.2
D10	0.074 ± 0.000	<0.001	0.713	9.62E-08	169.9	0.548 ± 0.069	1.108E-05	237.94 ± 27.44	4.55E-06	0.925	5.25E-12	179.8

K, α and β are the model constants values ± SD, $t_{(1/2)}$ is the half bowl time in seconds.

In this study, are present mathematical models for determination the kinetic of the texture across the time and we proposed the half bowl life calculation ($T_{1/2}$) to estimate bowl life in function of time, which (in analogy of half shelf life unit) to be defined as the period of time to sample loss the middle of its initial hardness, and in these way $T_{1/2}$ must be expressed in time units. In Table 7 are presented the parameter obtained by modeling the harness of the snacks (soaking in milk) in function of time. It was used (a) the fundamental general kinetic equation for shelf life prediction for second order (zero and first orders are not presented because they had very low R^2 values, thus theses model and are not appropriated to describe the phenomena), that will be name as FKEso and (b) Weibull probabilistic model, in Figure 2 are present the kinetic for all treatments to enable the shape visual comparison for treatment, curves represent the hardness in function of time and also it is available the $T_{(1/2)}$.

The lowest R^2 values for FKEso had obtained by D9 and D10 treatments with 0.710 and 0.713 respectively, following by D8, for the other treatments R^2 values varied from 0.912 to 0.985. In this way it is evident that the FKEso reflect significant models for most of treatments due according to Rani et al. (2016), R^2 values greater than 0.75 could indicate good significance of the model, these was corroborate for p values from de model which was significant ($p<0.05$) for all treatments with very small p values. Even FKEso resulted in adequate models, Weibull probabilistic model had by far the best process description presenting R^2 values greater than 0.925 with statistical significance ($p<0.05$) for the models.

In Weibull probabilistic model the value C_0 represent the initial instrumental texture measurement, which had a widely range of values depend on the each treatment, on the other hand C_∞ represent the value of instrumental hardness when the time trends to infinity, it could be intuitive to think that the C_∞ have to be zero, but, when these value (zero) was assuming for fitting the curve, the R^2 values became much lower resulting in not significant models, thus, for model accuracy improve, the C_∞ was assumed as the last instrumental measurement at a final time, these was also motive due generally a mathematical model is valid in data rage in which it was fitted.

The calculation for the $T_{1/2}$ for both models are presented in equations 13 and 14, there were numerical differences between the $T_{1/2}$ for both models even in cases where their R^2 values were closed, thus, taking into account that Weibull models were better, $T_{1/2}$ was assumed as function of Weibull model.

$$t_{1/2} = \frac{1}{k.C_0} \qquad (13)$$

$$t_{1/2} = \beta.\sqrt[\alpha]{Ln\left(\frac{C_0 - C_\infty}{\frac{C_0}{2} - C_\infty}\right)} \qquad (14)$$

$T_{1/2}$ ranged from 10s for D1 to 267,5s for D8, in general the $T_{1/2}$ became higher by the sugar addition, and these was also reported for other studies e.g. Gregson e Lee (2002), who related that bowl life could be increased by changes in manufacturing process such as sugar increasing. On the Other hand, the treatments with more percentage of tannin sorghum on their formulation trends to had less $T_{1/2}$, as was mention above, these could be due the tannin-sugar complexation, further investigation must be done to probe where or not it happens.

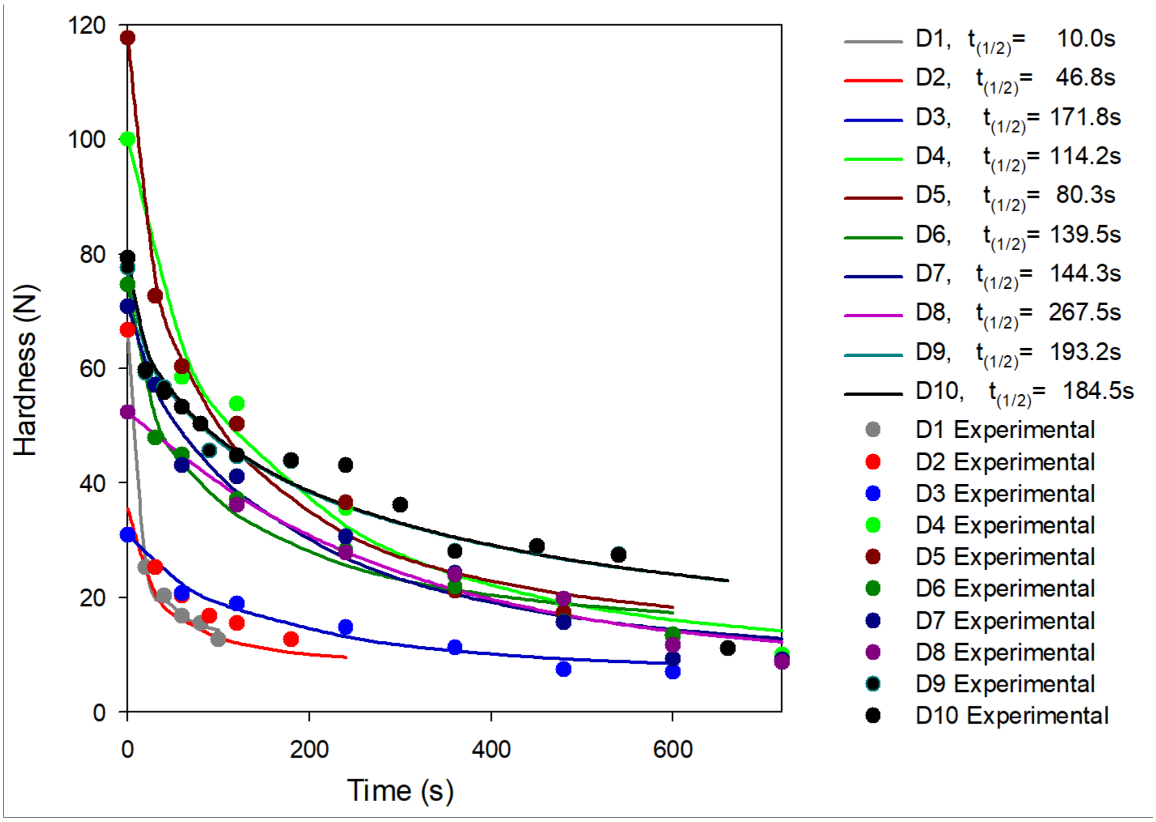

Figure 2. Bowl life kinetics to Weibull model by instrumental hardness (N) measurements per time (s) and half bowl life ($t_{1/2}$), for snacks using mixtures of sorghum BR305, BRS373 and sugar.

It was carried out PCA for 13 variables (Figure 3) including variables related to antioxidant capacity, extrusion properties and sensory acceptance, in order to better understand the relation among then, The two components explain ~75% of the experiment variance (PC1 and PC2 with values of 55.1 and 18.5 respectively), it is possible to observe that de treatment D1 (Figure 3b) with 90% of tannin sorghum BR305 and no sugar had the greater values of antioxidant properties (Figure 3a), following by D2 and D6 both also had 90% of tannin sorghum but also have sugar and non-tannin sorghum BRS373.

The antioxidant variables were those that presented more influence in treatments differentiation following by some extrusion properties variables and sensory acceptance, on the other hand crispness and SEI were lowest influences in the first two PCs. PCA and clustering techniques are some of the multivariate statistical methods that are strongly recommended to better understand the correlation among multiple responses (GRANATO et al., 2014).

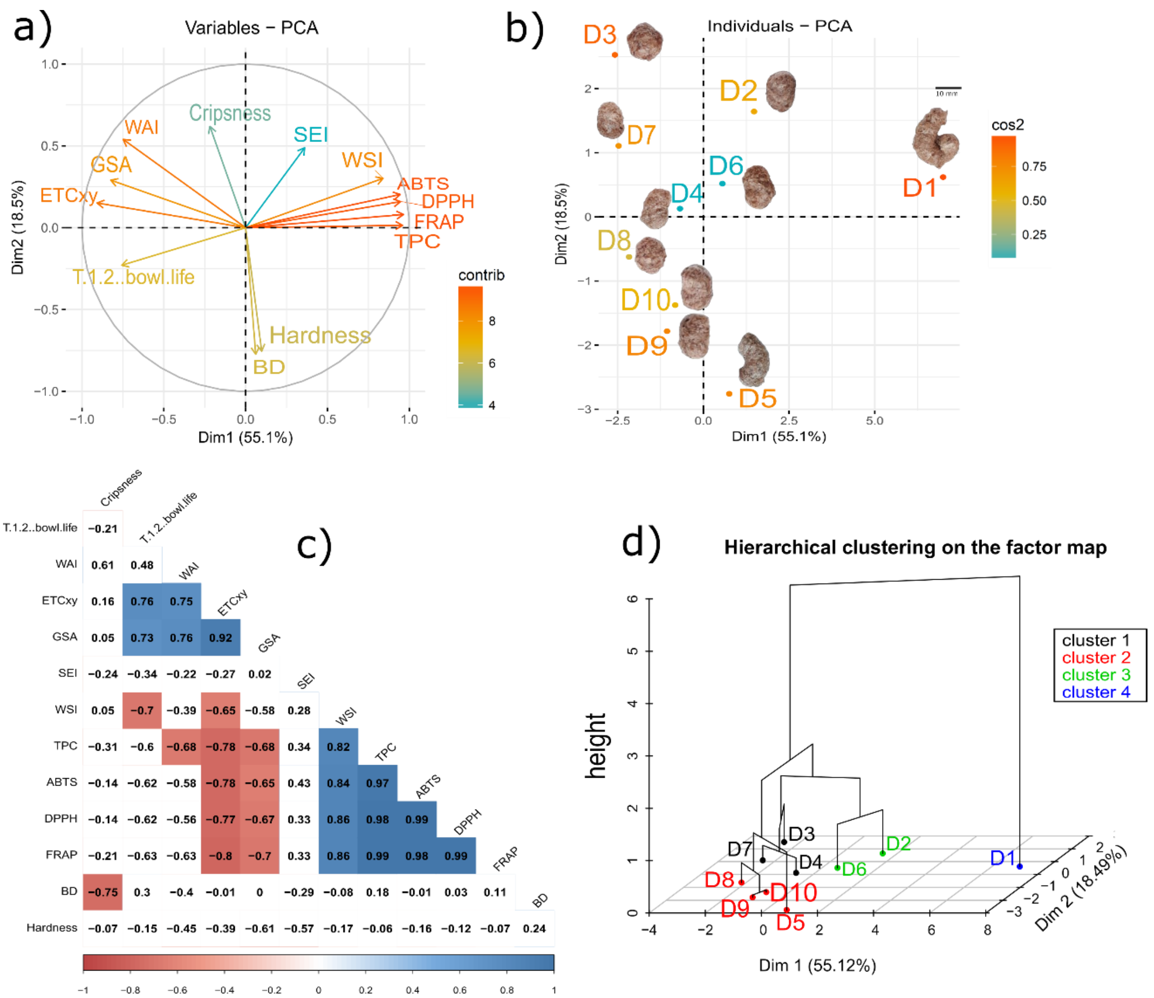

Figure 3. Multivariate statistic for extruded and antioxidant responses including general sensory acceptance for snacks making with sorghum BR305, BRS373 and sugar at different proportions. Principal component analyses for Variables (a) and treatments (b). Correlogram (c) with Pearson coefficient correlation from variables, numbers without background have no significant correlation (p>0.05), number with red or blue background in Table body indicate negative and positive significant correlation (p<0.05) respectively. Finally, hierarchical clustering from principal components (d).

As was previously mentioned antioxidant responses had a very high and positive correlation (Figure 3c), the correlation between TPC and antioxidant measurements was widely reported by many studies (AWIKA et al., 2003; RAGAEE et al., 2006; CHÁVEZ et al., 2017), on the other hand antioxidant variables (TPC, ABTS DPPH and FRAP) presented a negative moderate correlation with GSA with r values of -0.68, -0.65, -0.67 and -0.70 respectively, as will discussed later in CATA section, the consumers were able to perceive the residual taste of compounds such us tannins and TPC. GSA present high positive correlation with $T_{1/2}$, WAI and ETCxy with values of 0.73, 0.76 and 0.92. The values for scale Pearson correlation scores were taken from (MUKAKA, 2012).

Hierarchical clustering on the principal component is a useful statistical tool that permit form sample groups with similar response characteristic after principal component analyses, thus it was formed four groups of treatments, sample D1 (blue) was lonely due its biggest values of antioxidant responses. Red group was formed by samples with similar formulation with ~45-50% of each grain, the green group was formed by samples with 90% of tannin sorghum and 5 or 10% of sugar, and the last group was formed by samples with 90 of non-tannin sorghum with f levels of sugar. The resulting groups were very distributed by their responses and were according with their formulation.

Sensory results

The consumer socio-demographic characteristics are presented in Table 8, mostly people age from 18 to 45 years old (80%), the highest education level was incomplete pos-graduation 47.4% and the predominant income was 40% for 1 to 5 MBW, 21.1% for >5 to 10 MBW and 27.4 for >10 to 20 MBW. Finally the highest frequency of consumption for expanded snack was never, rarely and weekly with 13.7, 48.4 and 34.7% respectively.

Two consumers groups were formed based on sensory acceptance means for hierarchical clustering (Figure 4a), the first group had 74 members and second one had 31 members, regarding the GSA, both groups presented the same profile around the samples with the difference means, the first group expressed the greater sensory acceptance values (Figure 4b), and the second group was the lower sensory acceptance means these could be explained due the second group has been formed with a biggest proportion of people who had less consumption frequency of snacks (rarely consumption frequency of ~60%), another situation that could explain is that these second group had a very higher proportion of people that never listened about sorghum (85.7%). In general consumers opined that the sorghum utilization in daily consumption is good, very good and extremely good idea (26.3, 34.7, 22.1% respectively).

Table 8. Consumers (n=101) socio-demographic profile, expressed in %.

Category	Total [a]	Group 1 (n=74)	Group 2 (n=21)
Gender			
Female	70.5	73.0[a]	61.9[b]
Male	29.5	27.0[a]	38.1[b]
Age group (years)			
18-25	16.8	4.1[a]	19.0[b]
26-35	37.9	16.2[a]	28.6[b]
36-45	25.3	40.5[a]	38.1[b]
46-55	11.6	21.6[a]	9.5[b]
56-65	5.3	12.2[a]	4.8[b]
>65	3.2	5.4[a]	0.0[b]
Education			
Incomplete high school			
Complete high school	3.2	4.1[a]	0.0[b]
Incomplete graduation	8.4	18.9[a]	23.8[b]
Complete graduation	20.0	6.8[a]	14.3[b]
Incomplete post-graduation	47.4	24.3[a]	9.5[a]
Complete post-graduation	21.1	45.9[a]	52.4[b]
Income minimum Brazilian wage (MBW)[a] = R$954.00			
1 to 5 MBW	40.0	31.0[a]	33.3[a]
>5 to 10 MBW	21.1	15.0[a]	23.8[b]
>10 to 20 MBW	27.4	22.0[a]	19.0[a]
>20 to 30 MBW	9.5	5.0[a]	19.0[b]
>30 MBW	2.1	1.0[a]	4.8[b]
Frequency consumption of expanded cereal			
Never	13.7	11.0[a]	9.5[a]
Rarely	48.4	34.0[a]	57.1[b]
Weekly	34.7	27.0[a]	28.6[a]
Often	1.1	1.0[a]	0.0[a]
Daily	2.1	1.0[a]	4.8[b]
Do you know or have you listened all about sorghum?			
No	13.7	10.0[a]	14.3[b]
Yes	86.3	64.0[a]	85.7[b]
What do you think about the idea of introducing sorghum or its derivatives in food?			
Bad	1.1	0.0[a]	4.8[b]
Neither bad nor good	15.8	14.9[a]	19.0[b]
Good	26.3	25.7[a]	28.6[a]
Very good	34.7	36.5[a]	28.6[b]
Extremely good	22.1	23.0[a]	19.0[a]

Different letters in the same row indicates statistical differences between groups (p<0.05) by t test.

Samples D3 and D8 presented the biggest values of sensory acceptance with ~6.0 (Figure 4c) with no statistical differences (p>0.05), theses average score means I like this moderated. On the other hand the treatment with 90% of tannin sorghum and 0% of sugar presented de lowest GSA of 3.4, following by D4 and D5 (also 0.00% sugar) with GAS values of 4.4 and 4.1 (both D4 and D5 with not significant differences p>0.05).

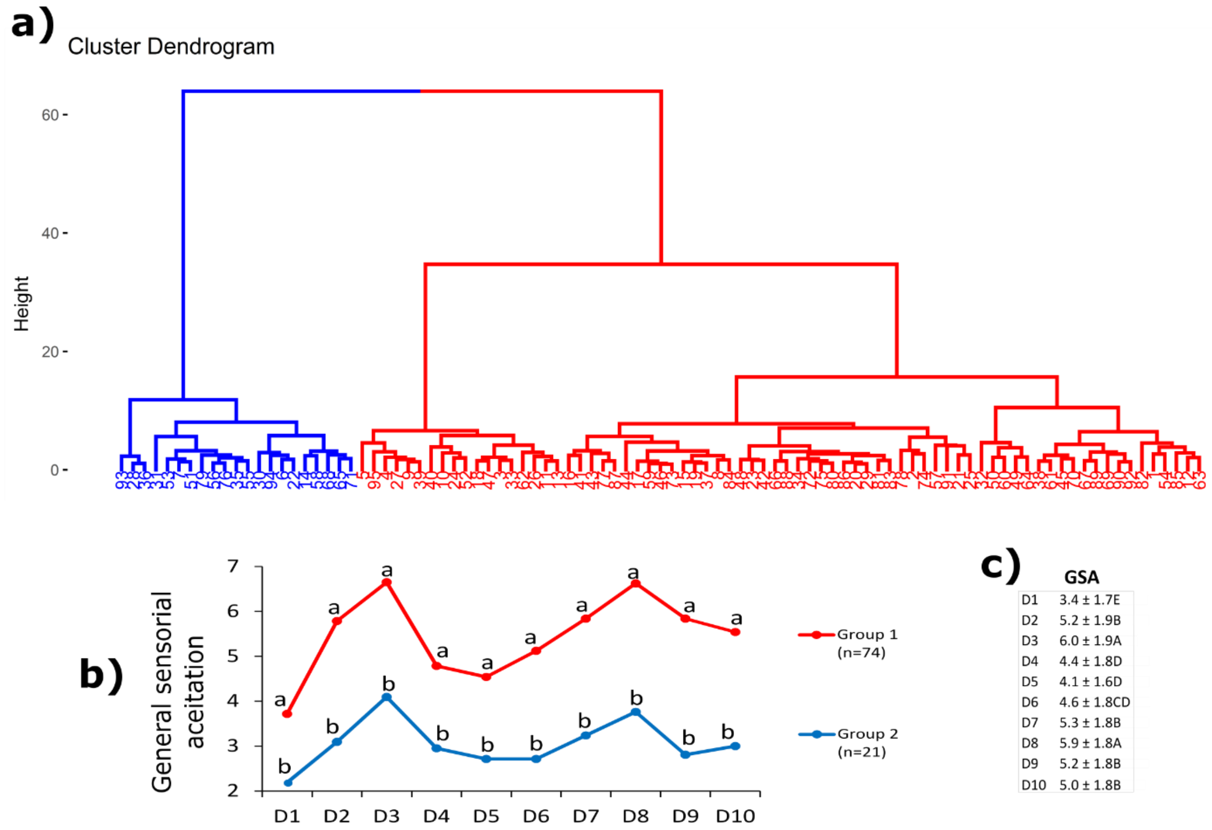

Figure 4. Groups formed by hierarchical cluster analyses of the consumers (a). General sensory acceptation for both the two groups and total (b, c respectively), different small letters in the same column (b) means differences between groups (p<0.05) for each treatment. The same capital letter in columns (c) express no statistical differences (p>0.05) among treatments for total number of consumers.

Regarding to CATA question results (Figure 5a and Table 9), treatments D1, D4 and D5 (with no sugar in their formulation) were most related with bad sensory attributes such as irregular appearance (46, 49 and 48 respectively), irregular shape (88, 56 and 78 respectively), unpleasant odd/flavor (28, 18 and 15 respectively), burnt residual flavor (37, 20 and15 respectively), no sugar/sweet (70, 70 and 71 respectively), and soft (53, 39 and 46 respectively), these results are in contrast with other studies, which affirm that the tannin presence do not negative influence in the acceptance of sorghum made products such as drinks (QUEIROZ et al., 2018) and cereal breakfast when compared sorghum and wheat (ANUNCIAÇÃO et al., 2017). The samples D3 and D8 were arranged in the same group by the hierarchical clustering from principal components (Figure 5b), as was explained above, both samples were the most linking with the better attributes and these coincide with the highest GSA scores (Figure 4c) with no significant differences between both samples.

Table 9. Total accumulated score for the attributes from CATA question in the sensory evaluating for the snacks made from different proportion of tannin and non-tannin sorghum and sugar.

Tretaments	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Dark points	12^{c}	23^{a}	28^{a}	12^{c}	14^{c}	19^{b}	21^{b}	24^{a}	20^{b}	20^{b}
Dark brown color	36^{a}	46^{a}	31^{b}	12^{c}	19^{c}	29^{b}	9^{d}	42^{a}	33^{b}	20^{b}
Light brown color	43^{e}	36^{f}	49^{c}	70^{a}	60^{b}	53^{c}	72^{a}	38^{f}	47^{c}	58^{b}
homogeneous appearance	10^{b}	11^{b}	19^{a}	9^{b}	9^{b}	11^{b}	18^{a}	18^{a}	21^{a}	16^{a}
Irregular appearance	46^{a}	39^{b}	30^{c}	49^{a}	48^{a}	38^{b}	28^{c}	23^{d}	28^{c}	36^{b}
Spherical shape	1^{c}	8^{c}	49^{a}	2^{c}	2^{c}	2^{c}	6^{c}	22^{b}	3^{c}	3^{c}
Oval shape	4^{e}	28^{d}	25^{d}	35^{c}	12^{e}	44^{c}	61^{a}	55^{b}	68^{a}	63^{a}
Irregular shape	88^{a}	59^{b}	17^{d}	56^{b}	78^{a}	49^{b}	27^{c}	21^{c}	21^{c}	28^{c}
Characteristic cereal aroma	13^{c}	19^{b}	18^{b}	18^{b}	11^{c}	17^{b}	18^{b}	24^{a}	19^{b}	22^{b}
Without aroma	31^{a}	16^{c}	20^{b}	25^{b}	33^{a}	23^{b}	21^{b}	22^{b}	29^{a}	31^{a}
Weak aroma	21^{b}	30^{a}	37^{a}	36^{a}	34^{a}	38^{a}	31^{a}	33^{a}	36^{a}	24^{b}
Roasted aroma	20^{a}	13^{b}	8^{b}	19^{a}	15^{b}	14^{b}	15^{b}	10^{b}	13^{b}	14^{b}
Popcorn aroma	24^{b}	20^{b}	17^{b}	30^{a}	21^{b}	18^{b}	31^{a}	14^{b}	15^{b}	11^{c}
chocolate aroma	3^{b}	15^{a}	17^{a}	0	4^{b}	4^{b}	9^{b}	18^{a}	8^{b}	8^{b}
Sweet aroma	4^{d}	25^{a}	22^{a}	3^{d}	5^{d}	9^{c}	15^{b}	23^{a}	15^{b}	6^{d}
Characteristic snack flavour	15^{c}	24^{b}	35^{a}	27^{a}	23^{b}	22^{b}	30^{a}	29^{a}	28^{a}	28^{a}
Sweet taste	0	25^{a}	26^{a}	2^{c}	3^{c}	11^{b}	10^{b}	30^{a}	8^{b}	11^{b}
Nice flavour	3^{d}	22^{b}	38^{a}	10^{d}	6^{d}	9^{d}	23^{b}	31^{b}	17^{c}	14^{c}
Mild taste	16^{e}	40^{c}	51^{a}	32^{d}	26^{e}	35^{d}	47^{b}	58^{a}	44^{c}	45^{c}
Unpleasant odd/flavour	28^{a}	13^{b}	1^{c}	18^{b}	15^{b}	12^{b}	5^{c}	4^{c}	13^{b}	15^{b}
Bitter residual taste	25^{a}	9^{c}	0	10^{c}	11^{c}	18^{b}	6^{d}	4^{d}	7^{d}	11^{c}
Burnt residual flavour	37^{a}	21^{b}	0	20^{b}	15^{c}	12^{c}	12^{c}	4^{d}	9^{d}	9^{d}
no sugar/sweet	70^{a}	19^{c}	21^{c}	70^{a}	71^{a}	43^{b}	42^{b}	14^{c}	50^{b}	47^{b}
Little sweet	27^{c}	58^{a}	55^{a}	27^{c}	28^{c}	46^{b}	55^{a}	57^{a}	45^{b}	48^{b}
Soft	53^{a}	29^{c}	24^{c}	39^{b}	46^{b}	33^{c}	27^{c}	26^{c}	30^{c}	26^{c}
Crunchy	30^{d}	76^{a}	84^{a}	53^{b}	43^{c}	70^{b}	82^{a}	82^{a}	79^{a}	71^{b}
Expanded	35^{b}	32^{c}	41^{a}	38^{b}	30^{c}	38^{b}	35^{b}	33^{c}	38^{b}	37^{b}
Dissolves in the mouth	37^{b}	39^{b}	51^{a}	33^{c}	42^{b}	42^{b}	44^{b}	36^{c}	40^{b}	32^{c}
Sticky on teeth	70^{a}	63^{b}	40^{d}	52^{c}	72^{a}	66^{b}	45^{d}	50^{c}	56^{b}	57^{b}
Aerated / biscuit sprinkles	35^{d}	47^{c}	58^{a}	50^{b}	31^{e}	44^{c}	46^{c}	42^{c}	44^{c}	50^{b}

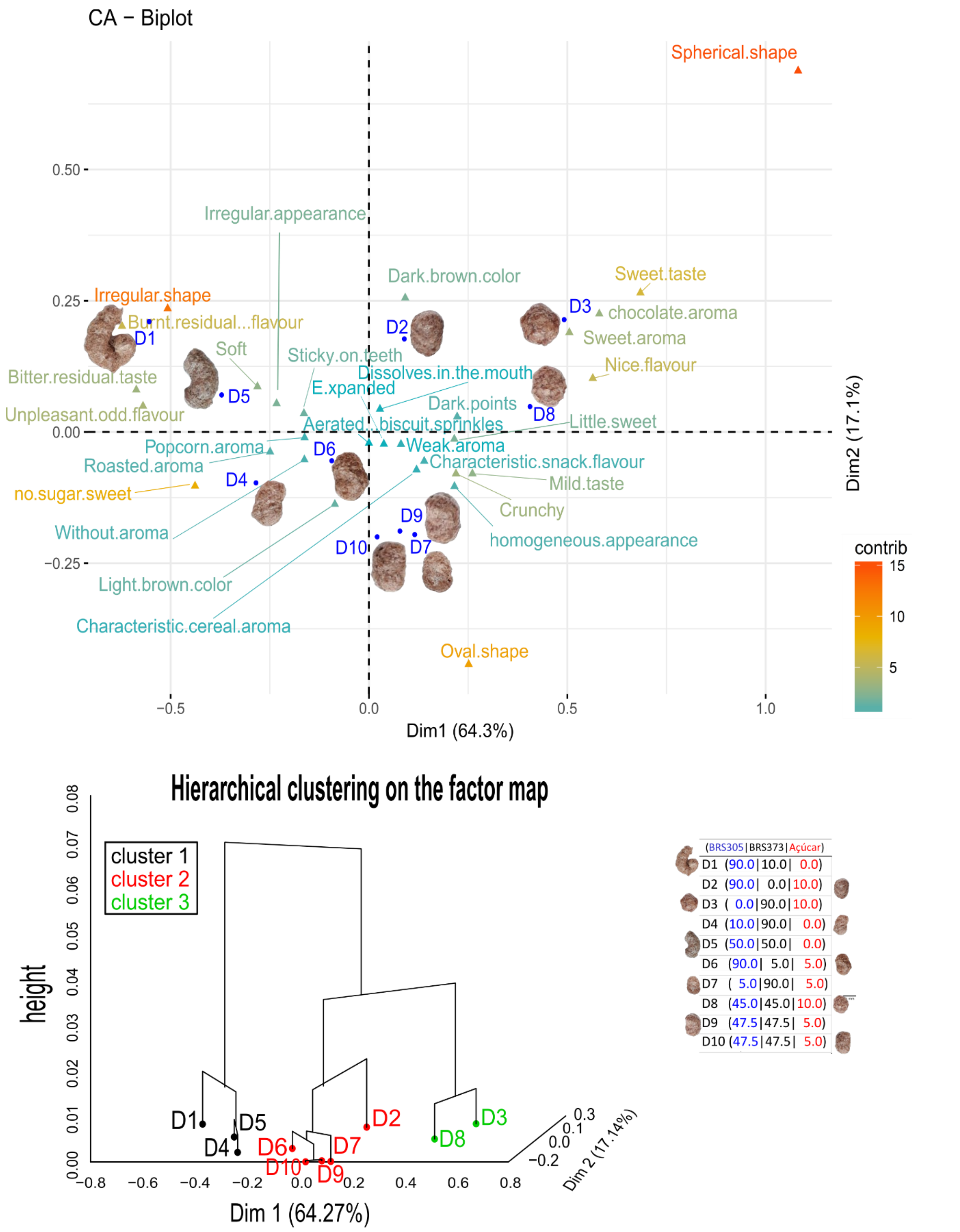

Figure 5. Corresponsal analysis usin CATA questions (a), and the hierarchical clustering from principal components (b).

On the other site samples D3 and D8 were most related to spherical shape (49 and 22 respectively), chocolate aroma (17 and 18 respectively), sweet taste (26 and 30 respectively) and nice flavor (38 and 31 respectively). Observing the p values of the sensory attributes in Table 8, it could be affirm that the attributes that differentiate the samples were: irregular shape, spherical shape, oval shape, no sugar/sweet, crunchy following by nice flavor, sweet flavor, dark and light color, burnt residual flavor, mild taste, sweet aroma, unpleasant odd/flavor and chocolate aroma, in this order.

Multiple factor analyses results

Finally, it was carried out a MFA for better understanding the interaction of the majority of the studied variables. The variables were arranged in four numerical groups by their similarities, the first group was formed for CATA questions (30 variables), the second group (sensory acceptance) (1 variables), the third group (Extrusion properties) was regarding to extrusion properties (8 variables) and the fourth group (antioxidants) was made by antioxidant variables. Additionally, one categorical variable was created, called Sugar (with three levels: 0% sugar, 5% sugar and 10% sugar) due the importance of the sugar levels in the sensory responses.
The first and second dimensions of MFA explained 55.45 and 17.40% of the variability respectively, totalizing 72.83%. The correlation circle formed by all variables in MFA is displayed in the Figure 6a. It is clear that the antioxidant responses were very close related among them and had a priority role in the samples classification, thus sample D1 had a very high influence by antioxidant (it is observed by a big line in Figure 6b, in addition, sample D1 is in the same place to the antioxidants when compared Figures 6a and 6c). Observing the Figure 6c, it is evident that the sugar level was important in the consumer preference. Finally as D3 and D8 was similar in acceptance.

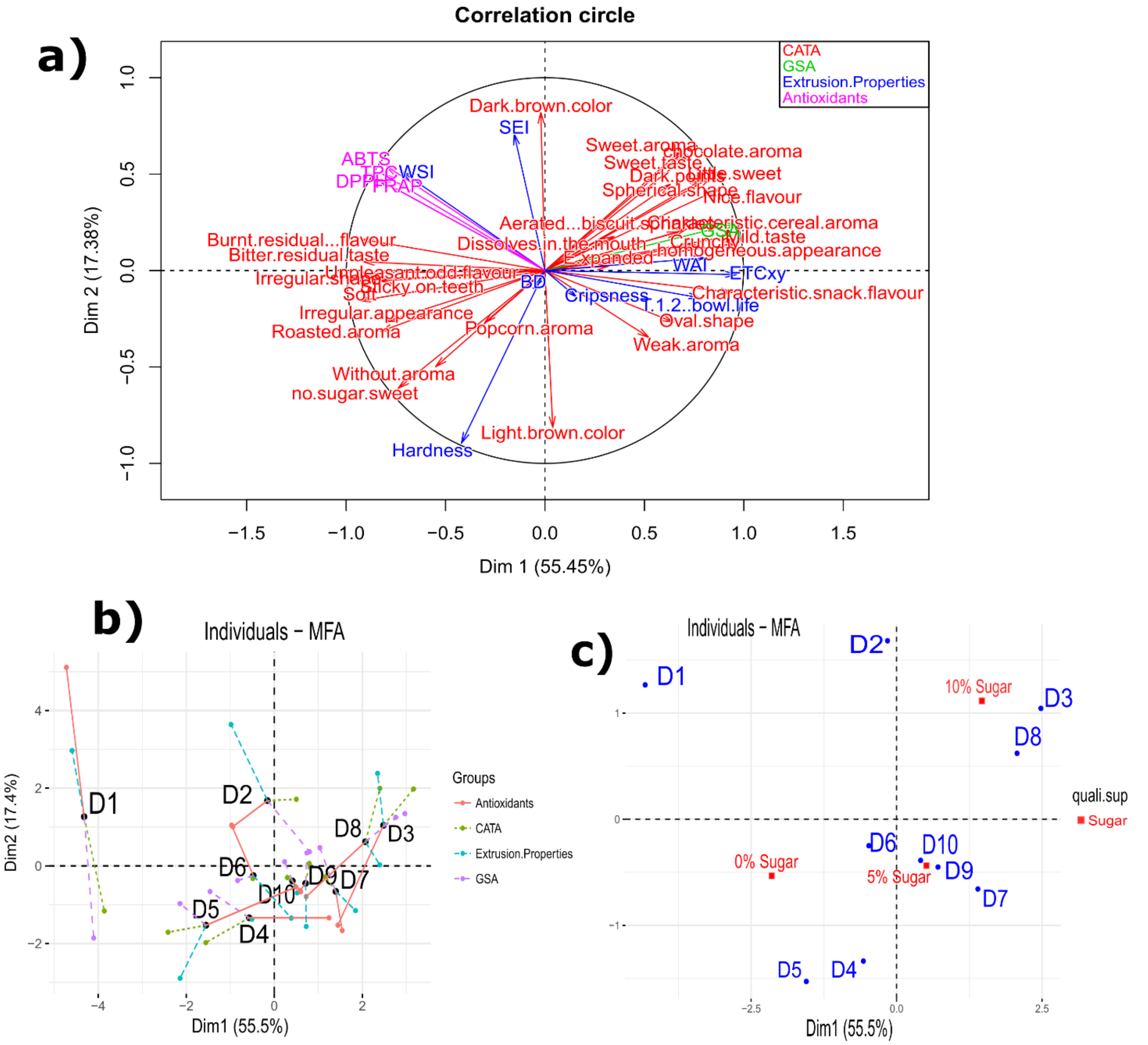

Figure 6. Multiple factor analysis (MFA) using four groups of variables, the groups was forming by atioxidant responses, CATA question, Extrusion properties and general sensory acceptance. In (a) is presented the circle correlation for all variables, in (b) the MFA map for the four variables groups. Additionaly it was used the amoung of sugar as a auxiliary and categorical variable, its result is in (c).

Optimizing snacks with a mixture of tannin and non-tannin sorghum and sugar

Finally (Figure 7) the desirable function was used to optimized TPC, GSA and $T_{1/2}$ variables, those variables were selected because they represent well different group of variables, e.g. as TPC has very high Pearson correlation with antioxidant variables (was observed above), GSA for sensory responses including CATA and finally higher value of $T_{1/2}$ is a very strong desirable response. The desirability for responses was conFigured at maximum, and the result of the function recommended 76.5% of the BR305 (tannin sorghum), 13.5% of BRS373 and 10% of sugar, the desirability value was 0.51, that amount is not high, but it would be very advisable further investigations to test that mixture.

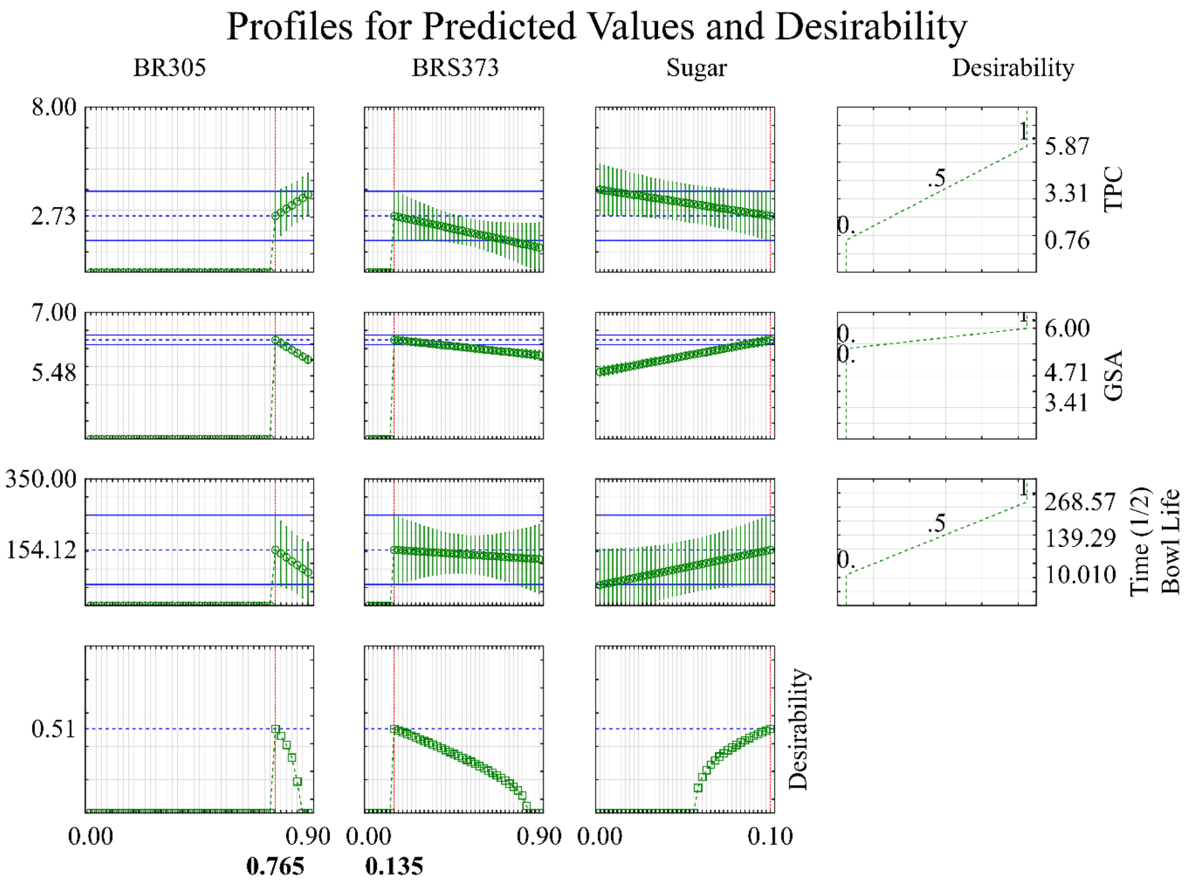

Figure 7. Desirability function for optimization the total phenoplic contend, general sensorail acptation and half bowl life ($t_{1/2}$) responces by the mixture of sorghum BR305, BRS373 and sugar.

CONCLUSIONS

Snack with 90% of tannin sorghum (BR305) presented the highest levels of total phenolic compounds and antioxidant capacity, also it presented low SEI, high WSI and low bowl life, as well as the lowest sensory acceptance, whereas rich blends of non tannin sorghum presented the opposite responses. Optimized blend consisted of 45% of tannin sorghum, 45% non-tannin sorghum and 10% of sugar that scored 6 of a 9 points sensory scale. By applying desirability function it was found the optimized blend would be 76.5% of BR305 (tannin sorghum), 13.5% of BRS373 and 10% of sugar. But, it was also found that higher sugar content would provide higher sensory scores of acceptability.

In addition, a lack a good bowl life determination was found to be relevant to measure this property, thus it was proposed a method of measuring half bowl life by using Weibull probabilistic model that should be expressed as function of time.

The best acceptance scores of tannin and non-tannin sorghum provides a good indication that whole grain sorghum has a great potential of functional food interesting for cereal grains that fulfill the nutritional quality of wellbeing food.

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A new sensory bowl life methodology compared to instrumental bowl life

Resumo

Um dos principais atributos de qualidade considerados quando se consome cereal matinal é a sua Crocância (textura) depois de um tempo misturado com um líquido, este atributo é chamado tempo de tigela, determinado. Foram determinadas a textura instrumental e sensorial para a avaliação da vida média de tigela de uma amostra de extrudado a partir de farinha de grão inteiro de sorgo em forma de bola e uma amostra comercial em forma de bola. Foram aplicados modelos probabilísticos de Weibull tanto para a análise instrumental quanto para a sensorial, demonstrando excelente ajuste ($R^2 > 0.97$), porém foram encontradas diferenças substanciais em relação à previsão do tempo de tigela. Finalmente, foram propostas duas formas de se medir o tempo de tigela: (a) o tempo médio de tigela instrumental ($IBT_{1/2}$) o qual seria aconselhável como uma metodologia rápida de comparação de amostras, e (b) o tempo médio de tigela sensorial ($SBT_{1/2}$) seria indicado quando o objetivo principal é predizer o período de tempo real antes que o consumidor rejeite uma amostra por falta de crocância após a amostra ser mistura com um líquido.

Palavras-chave: distribuição probabilística de Weibull, meia vida instrumental, meia vida sensorial, análise de sobrevivência, modelo matemático

Abstract

One of the main quality attribute considered when consuming breakfast cereal soaked in a liquid is the crunchiness at the consumption. Instrumental and sensory texture were carried out to determine bowl life as a function of time of ball shaped whole grain sorghum extrudates and a commercial breakfast ball shaped sample. Weibull probabilistic models were applied for both instrumental and sensory analyses demonstrating excellent adjustment ($R^2 > 0.97$); however substantial differences regarding half bowl life prediction were detected. It was proposed two ways of bowl life measurement: (a) instrumental half bowl life ($IBT_{1/2}$) suits when fast-easy-to-use methods is required to compare samples, and (b) sensory half bowl life ($SBT_{1/2}$) is indicated when the main objetive is to predict the real time period before consumer rejects a sample.

Keywords: Weibull probabilistic distribution, instrumental half bowl life, sensory half bowl life, survival analyses, mathematical model

INTRODUCTION

Even though, bowl life seems easy and intuitive to define, different sources propagate different definitions about bowl life, e.g., Anderson et al. (2003), “bowl life is the snack texture retention in milk”, without including time. Zhang et al. (2014) express bowl life as sample crispness after 5 min soaking and reported in kg/s, here the result is not the time, Brennan et al. (2012), reported, that “the hydration pattern is a good demonstration of the potential bowl life (defining hydration pattern as de g of water absorbed per g of extruded sample after 2 min soaking), additionally the author also said, the low hydration degree result in a prolonged bowl life, but did not defined bowl life and the time of rejection, Brennan et al. (2013), mention, in food extrusion products is import and obtained snacks with enough bowl life, thus the consumer of these products remain crisp for a long time, leaving understood that bowl life is the limit time in which the snack is still acceptable for consumers as function of its crisp after soaking with a liquid.

Another definition for bowl life is was found as: the loss of brittle texture as the gain of moisture the snack turns soggy (NELSON; LABUZA, 1993; MACHADO et al., 1999), in this context, one again, it is not consider at time in which the quality parameter is loss,

Machado et al. (1999) and Gregson; Lee (2002), have done a really hard work using mathematical modeling for study the effect of fat and total solids concentration on the kinetics of moisture uptake by commercial puffed corn and breakfast cereals, the authors applyed Weibull probabilistic model to described the moisture uptake by their samples, nevertheless, the rejection time was not modeling or calculated.

Since the moisture uptake depends on the liquid composition, temperature, snack composition and structure and the physical methods became tedious, complex and delayed.

Recently, the bowl life is being more used, e.g. Oliveira et al. (2017), allay a bowl life test (without antiquated any references about methodology), which consisted in the measurement of the sample crispness after soaking in whole drink (3g/mL) at 5°C for 3 min and then drained for 10 s, and Oliveira et al. (2018), used the same methodology. The results were expressed in terms of hardness and crispness, where hardness was the peak force (N), and crispness is the total numbers of peck, in both cases, was not measurement the time in which the sample would be rejected by consumers for lack of crispness.

On the other hand, the major cause of breakfast cereal rejection is the losses of its crispness due the adsorption of the moisture in the ambient or by the mass transfer after soaking it with a liquid (SAELEAW; SCHLEINING, 2011; ZHANG et al., 2014), thus, bowl life became in a crucial characteristic that defines consumer preference (ZHANG et al., 2014).

Gregson; Lee (2002), defined bowl life as “the length of time that a breakfast cereal retains its crispness while immersed in milk”, In this way it could be possible to extend the BOWL LIFE definition as: the time period for a breakfast cereal (or similar product) retain its desired texture for consumers after soaking in a liquid (water, milk, yogurt or whatever liquid in which it will be consumed) at a determinate temperature and the results must be expressed in term of the “time”, It important to note that, no body in the above examples of bowl life really calculate the time period in which the sample is rejected by the texture loss (bowl time).

On the other hand, sensory analysis is much used to evaluated some characteristics from food products such as chips, or puff cereal, consumers have enough sensitive and are able to describe the differences between crisp and crunch by the sound: the sound for the first one is short and for the last one is more long lasting (SAELEAW; SCHLEINING, 2011).

Survival analysis is a statistical tool extensively used in diverse areas as clinical, epidemiological, biological among others, in survival studies the subjects are accompanied by the occurrence of the even of interest since they are diagnosis of an illness (CRUZ et al., 2010), Survival analysis consist of evaluating times until one characteristic of interest its present, or in the other words, the measurements could be done until rejection time (HOUGH et al., 2004), the survival analysis could be consider as a low cost and fast-easy-to-use-method, This methodology is widely used to predict the shelf-life of foods, and the result are really expressed in time (CRUZ et al., 2010; RICHARDS et al., 2016; GIMÉNEZ et al., 2017; OLIVARES-TENORIO et al., 2017; S. et al., 2017).

Despite the bowl life importance, there are few scientific literature regarding to a good definition and methodology, thus, the bowl life definition and methodology are yet doubtful, Since, bowl life remains the “shelf live” which according to Fu e Labuza (1993), “is the time period for the product to become unacceptable from sensory, nutritional or safety perspectives”, According to (HOUGH, 2010), a more complete definition could be done by the Institute of Food Science & Technology, London (IFST, 1993), defining shelf life as “the time during which the food product will (a) remain safe; (b) retain desired sensory, chemical, physical and microbiological characteristics; and (c) comply with any label declaration of nutritional data, when stored under the recommended conditions", In some cases the shelf life is defined at laboratory without needing the interpretation of the consumers e.g. when it is necessary to know if a food is safe (must be free from pathogenic bacteria), another example could be the level of vitamin D of an enriched milk, which have to comply legislation, but in many cases the shelf life have to be defined as acceptable or unacceptable for the consumer (HOUGH, 2010), this is the case of bowl life.

The present research aims to use survival analysis to estimate the bowl life in terms of time and related it with texture mechanical testes.

MATERIALS AND METHODS

Two snack type were used to calculate the bowl life proposed in this work. The first one was the experimental sample making in our laboratory by extrusion cooking process using sorghum genotypes BR305 (tannin contend) and BRS373 (non-tannin) and the second snack was a commercial one, which was bought in the local marked.

Instrumental Bowl-life assay

It was used the methodology described by Oliveira et al. (2017) with modifications, the snacks were soaked in semi-skimmed milk (2.49 ± 0.15 g/10 mL) (1:4 v/v) at 10°C for different times (in order to obtain a hardness kinetics degradation curve and calculated the $t_{(½)}$:middle bowl-life or the middle time to get half initial hardness, this is a new measurement proposed in this study for real quantification of bowl-life in which the result is expressed in time units as its synonym expression "shelf-life”), samples were drained for 15s before the measurements, The test configuration was for the same for the texture snack assay, ten measurements were performed for each time.

Sensory Bowl-life assay

The sensory tests was performed by 100 consumers (40 males and 61 females), who included graduate and post-graduate students, researches and employees recruited at the Universidade Federal Rural do Rio de Janeiro. Ethical approval was provided by The Human Ethics Research Committee at Federal University of Minas Gerais, Brazil, approved this study (N° 03591312.0.0000.5149), Consumers were accommodated in individual tasting booths, where they received instructions about the test. They were asked to sign an Informed Consent Form, according to the Guidelines and Norms for Research with Humans, Resolution 466/2012 of the Brazilian National Health Council.

The experimental was carried out imitating as similar as possible the real domestic consumption conditions, Since, the volume of each sphere was different between samples, the amount of added sample were also different, thus, for the experimental sample was 14.67 ± 1.08 g/150 mL and for commercial sample was 24.49 ± 1.47 g/150 mL, with the aim to maintain a similar volume/volume proportion of 1:4 (imitating the home consumption).

A plastic bowl (total capacity of 200 mL) was given to participants containing the snack, and two plastic cup (one with 150 mL the water and the other one with 150 mL at ~10°C), then it was asked to each consumer, to put the milk inside the bowl, mixture experimented and answer the question, "Considering, the sample texture, are you willing to consume the product?, they had to respond the same question from 0 to 20 min with the interval of 2 min and 30 seconds, with a total of 9 times, in each time the two possible answers were "Accept" or "Reject".

Mathematical models

Contrary to the moisture uptake from the air, in this process, samples are stored until equilibrium reaching an homogeneous water activity throughout the sample, cereal texture after soaking into a liquid has bees describing have been defined as a rapid non-equilibrium because involve two transfer process, thus occur the moisture uptake and loss or uptake soluble solids (MACHADO et al., 1999; GREGSON; LEE, 2002), additionally the other factor could be temperature and composition (both liquid medium and beackfast cereal) and the solid structure. Machado et al. (1999), found that Weibull probabilistic model described the moisture uptake (Y) in function of the time (X) (pay attention, in this way, is not possible to calculate the rejection time for the loss of texture acceptation, because only was calculate the moisture uptake as a dependent variable).

In this work, was been calculated model for both, instrumental and sensory determination, were calculated for instrumental texture determination, the loss of hardness (peak force, as dependent variable) was adjusted in function of time (independent variables), and it was tested the classical model kinetics deterioration model and Weibull probabilistic model.

Thus the Weibull probabilistic model was also used to fit the hardness changes (equation 1), the equation was rearranged to model data in function of texture at any time (C_t) (equation 2).

$$\frac{C_t - C_0}{C_\infty - C_0} = 1 - e^{-\left(\frac{t}{\beta}\right)^{\alpha}} \qquad 1$$

$$C_t = C_\infty + \left(C_0 - C_\infty\right) 1 - e^{-\left(\frac{t}{\beta}\right)^{\alpha}} \qquad 2$$

Where, C_t is texture at time t, C_0 is texture at time zero, C_∞ is texture at infinity time, β is scale parameter, and α is the shape parameter.

For mathematical model in sensory survival analyses there also was used the rejection function for the Weibull distribution (equation 3 and 4).

$$F_{(t)} = 1 - e^{-\left(e^{\left(\frac{\ln(t)-\mu}{\sigma}\right)}\right)} \qquad 3$$

$$F_{(t)} = 1 - e^{-\left(\frac{t}{\beta}\right)^{\alpha}} \qquad 4$$

The relationship between μ and σ of this last equation and β and α from equations 1 and 2 is us following.

$$\sigma = {}^{1}\!/_{\beta} \qquad 5$$

$$\mu = \ln(\alpha) \qquad 6$$

Thus, either of the two expressions can be used (HOUGH, 2010). But in sensory case we used equation 3 due is widely used en sensory survival studies.

Data statistical analysis

Data were analyzed with using Statistica 10 software (StatSoft, Tulsa, EUA) and the software R for statistical computing, version 3.2.4 (CORE_TEAM, 2017).

RESULTS AND DISCUSSIONS

Determination of the half bowl time by instrumental measurement

The Weibull distribution for hardness instrumental measurements had high values of R^2 (97.90% and 97.70% for experimental and commercial samples respectively (Table 1) with significant regression ($p<0.05$) for both extrudates and commercial samples.

As it was expected the model parameters of the kinetics were very different in both samples, thus, the scale parameter β were 4.428 ± 0.360 and 7.813 ± 0.375 for experimental and commercial cereals respectively, since the β refers to scale parameter and the initial crispness for commercial sample was very higher (more than three times) than the extruded sample were (Figure 1), the β for both samples were also very different. On the other hand, the shape parameter α values were 0.968 ± 0.137 and 1.694 ± 0.204 respectively.

Table 1. Matematical model parameters for instrumental hardness meassumens and instrumental half bowl time $IBT_{(1/2)}$ estimation

Weibull for Instrumental reassume									
Treatment	α	SD	P for α	β	SD	P for β	R^2	P Regression	$IBT_{(1/2)}$ (min)
Experimental	0.968	0.137	0.001	4.428	0.360	<0.001	0.9790	<0.001	3.86
Commercial	1.694	0.204	<0.001	7.813	0.375	<0.001	0.9770	<0.001	8.55

Weibull equation using to uptake moisture by cereal snack breakfast immersed in milk has been reported as the model that accruements derived the changes in function of time (MACHADO et al., 1999; GREGSON; LEE, 2002), although the mentioned authors worked with Weibull distribution they did not described a methodology to estimate the time in which the sample loss its texture. For that reason in our previous work we proponed the half bowl life ($T_{(1/2)}$) for instrumental measurements $IBT_{(1/2)}$, which, for the moment, seems to be the better way to could express bowl life in function of time. Estimating the $IBT_{(1/2)}$ it is possible to compare different samples and could be a advisable tool to development products with higher $T_{(1/2)}$ values.

The $IBT_{(1/2)}$ value for the samples were 3.9 min for the extrudates make in our laboratory and 8.6 min for the commercial sample, this could be explained due the commercial sample had a protective layer (probably a sugar and chocolate). As was reported by Gregson; Lee (2002), the increased in bowl life may be done by changes in manufacturing process such us cereal morphology, addition of surface coating e.g. sugar or high molecular polysaccharides for increasing the glass transition temperature.

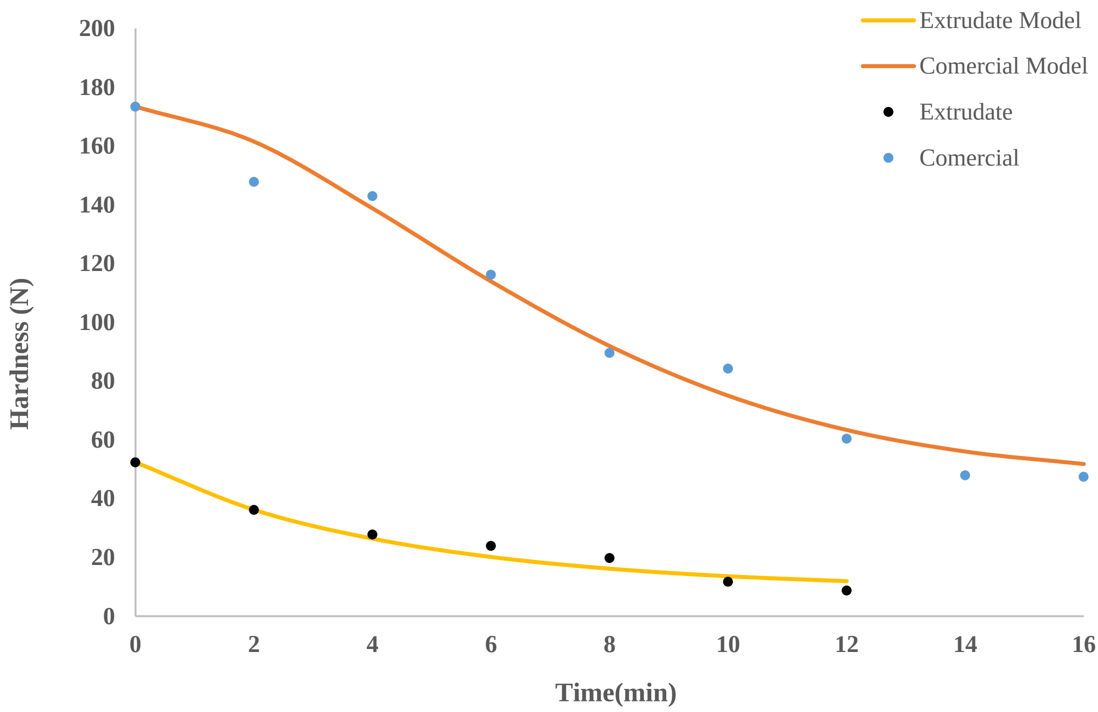

Figure 1. Instrumental hardness in funtion of time for extruded in laboratory and comercial samples.

Result for sensory half bowl time

Mechanical measurements are the most popular methodology for texture properties measurements (due they are quick and easy to apply), particularly in industry by the necessity for fast-easy-to-use-methods as was mention by Saeleaw e Schleining (2011), additionally, the same author, mention that Seymour (1985), reported, that using a Kramer shear cell in an Instron to crush humidified samples, results in not enough correlations between crispness and mechanical measurements including maximum force at failure. Another disadvantage when apply mechanical test is that most crisp foods cannot be tested due their irregular sizes, shapes or part of a food that including not crisp part e,g (stuffed cookie =biscoito rejeado) (SAELEAW; SCHLEINING, 2011).

The Weibull distribution for fitting the sensory data was higher values of R^2 (Table 2) that Weibull adjusted for experimental data. Thus, R^2 for extruded in lab sample was 0.9930 and for commercial sample was 0.9961, these results are very close two 1 which iniquities that Weibull distribution for fitting the sensory fitted very well sensory data results, in addition the p values for both model were also significant ($p<0.05$).

The model parameters for sensory Weibull distribution were different but a little closed for both samples, thus, μ presented values of 6.266 ± 0.032 for extrusion in lab samples and 6.434 ± 0.021 for commercial samples. On the other hand β values were 0.467 ± 0.041 for extrusion in lab sample and 0.474 ± 0.028 for the commercial sample.

Table 2. Matematical model parameters for sensory survival analises for crunchiness instrumental and sensory half bowl time $SBT_{(1/2)}$ estimation

	Weibull sensory								
Treatment	σ	SD	P for σ	μ	SD	P for μ	R^2	P Regression	$SBT_{(1/2)}$ (min)
Experimental	0.467	0.041	<0.001	6.266	0.032	<0.001	0.9930	<0.001	13.6
Comercial	0.474	0.028	<0.001	6.434	0.021	<0.001	0.9961	<0.001	14.9

The sensory half bowl time $SBT_{(1/2)}$ in Table 2 and Figure 2 was very much larger than the $IBT_{(1/2)}$ in Table 1. $SBT_{(1/2)}$ was almost 3.5 time than the $IBT_{(1/2)}$ for the experimental sample and ~1.75 time for commercial samples. Regarding to rejection sensory measurements, the $SBT_{(1/2)}$ were different but much closer (contrary to that was expected) between two samples (13.6 and 14.9 min for experimental and commercial sample).

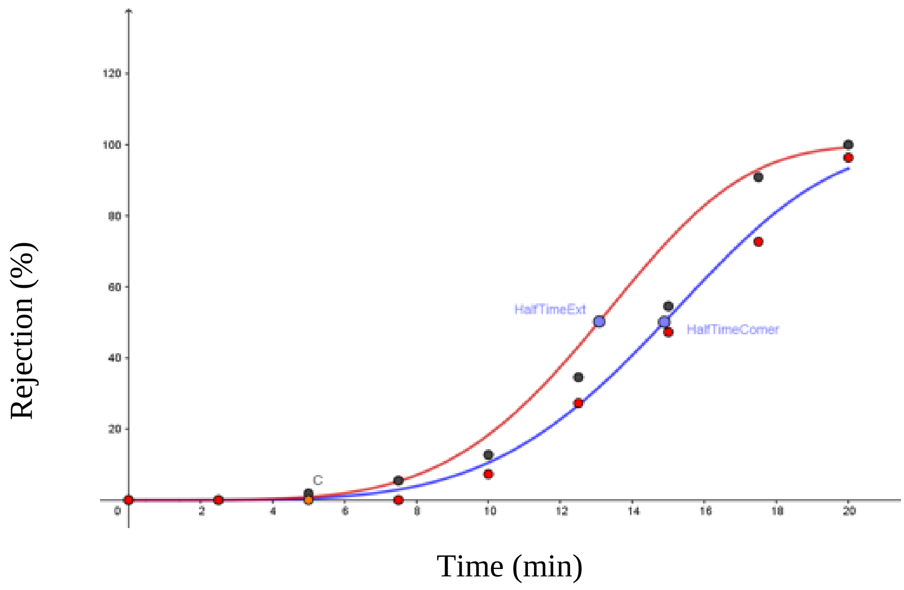

Figure 2. Sensory rejection in funtion of time for extruded in laboratory and comercial samples.

These result of the proximity in SBT$_{(1/2)}$ for both samples could be explain because (as was previosly mention) consumers are enough sensitive and able to describe perceive differences between crisp and crunch by the sound (SAELEAW; SCHLEINING, 2011), the results permit to affirm that the consumer are able to detect crisp and crunch for very much than the instrument after the sample were soaking in a liquid.

CONCLUSIONS

Bowl life must to expreset in terms of time, Wibull deterministic model using in kninetic for both instrumental and sensory bowl time analises probed to had a very good accurance for data modeling and consecuently the prediction of the half bolw time will be very usel for industry and reseachr files. But, there are differences beteen instrumental and sensory half bowl time ($IBT_{(1/2)}$ and $SBT_{(1/2)}$ respectively).

IBT(1/2) could be very useful when the aim is only the comparison among samples order to determinate which(s) sample are able to retain instrumental crispness and IBT(1/2) would a good tool for fast-easy-to-use-methods in orther to make, optimised or iven improve snack ceral products. But when the objetive is to determinate the realy time in which the sample will be rejected for the lack of texture after soaking in a liquid, $SBT_{(1/2)}$ would extrongly recommended.

GENERAL CONCLUSIONS

It was detected the needing for the using of sensory tests in researches which pretend to develop human foods using sorghum grain in order to obtain sensory acceptable products. Expanded snack made with tannin sorghum presented more functional properties (bioactive compounds and antioxidant capacity) but less sectional expansion and sensory acceptance, on the other hand non tannin sorghum had opposite response than tannin sorghum. The mixture of tannin and non tannin sorghum and the use sugar allow an expanded snack product with adequate functional properties (bioactive compounds and antioxidant capacity) as well as higher sensory acceptance. In addition there were proposed three new tests, a) extrusion transverse circularity, which was proposed to express how close is an expanded snack to an sphere, in this way when the value of extrusion transverse circularity were more close de one the shape of the expanded snack is more spherical, b) instrumental half bowl life ($IBL_{1/2}$), which finally allow to express the results of bowl life determination in time units and it will be very useful as a rapid method to compare samples, c) instrumental half bowl life ($SBL_{1/2}$) to determinate the time in which the sample will be rejected by the consumers based on the texture. Thus, there was made a complete study in order to developed a new expanded snack from sorghum, which finally presented functional properties (such as antioxidant capacity, tannin and phenolic compounds) and an adequate sensory acceptance, this ready to eat product, could be consume for all people even those who have different gluten intolerant disorders due whole sorghum is a gluten free cereal.

SUGESTIONS FOR FUTRURE WORK

A research to develop a roof from expanded snacks to obtain greater half bowl life and improve sensory acceptance, this roof could be done use some polymers adequate for human consumption.

Seasoning like sugar, salt and chocolate may be test as an alternative for improve the product acceptance.

It would be interesting to test the product in from different public type, may be children, fitness people, amount others.

Packing test would be interesting for study the effect of information o antioxidant capacity, gluten free, dietary fiber and price in the acceptances of the consumers.

It would be necessary a study about Brazilians sorghum neophobia.

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