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TESE

Efeitos de diferentes processamentos sobre a qualidade nutricional e funcional de grãos de milheto (*Pennisetum glaucum* (L.) R. Br.)

Amanda Mattos Dias Martins

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EFEITOS DE DIFERENTES PROCESSAMENTOS SOBRE A QUALIDADE NUTRICIONAL E FUNCIONAL DE GRÃOS DE MILHETO (*Pennisetum glaucum* (L.) R. Br.)

AMANDA MATTOS DIAS MARTINS

Sob a orientação do Professor
D.Sc. Carlos Wanderlei Piler de Carvalho
e

Co-orientação do Professor
D.Sc. Sidney Pacheco

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

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TESE APROVADA EM 21/02/2019

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"... Acredite nos seus sonhos, insista. Falaram para mim, que não era possível. Se começar foi fácil, difícil vai ser parar..."

(O Rappa)

RESUMO

DIAS-MARTINS, Amanda Mattos. **Efeitos de diferentes processamentos sobre a qualidade nutricional e funcional de grãos de milheto (*Pennisetum glaucum* (L). R. Br.), RJ.** 2019. 105p. Tese (Doutorado em Ciência e Tecnologia de Alimentos). Instituto de Tecnologia, Departamento de Tecnologia de Alimentos, Universidade Federal Rural do Rio de Janeiro, Seropédica, RJ, 2019.

Milheto é o sexto cereal mais produzido no mundo. No Brasil, apesar desta cultura estar adaptada as nossas condições agrícolas com cerca de 5 milhões de hectares plantados, sua produção é destinada apenas para alimentação animal e para cobertura vegetal (plantio direto). Possivelmente, um dos motivos para o não consumo humano esteja relacionado à falta de conhecimento acerca dos benefícios nutricionais e dos tipos de produtos que podem ser elaborados com o grão. Desta forma, o objetivo deste trabalho foi promover conhecimento sobre o potencial tecnológico e nutricional dos grãos de milheto (*Pennisetum glaucum* L.R.Br) para consumo humano no Brasil e avaliar os efeitos de diferentes processamentos nas propriedades químicas, físicas e nutricionais deste cereal. A tese foi subdivida em 3 capítulos, no Capítulo I, foi elaborado um extensa revisão bibliográfica sobre os grãos de milheto em relação à segurança alimentar, composição nutricional, processos tecnológicos, benefícios a saúde e produtos à base do grão. No Capítulo II, foram estudados os efeitos de dois métodos de cocção, aquecimento ôhmico (OH) (método emergente) e em panela aberta (método convencional) no rendimento, textura (TPA), na cor (C^*, h°, ΔE), índice de absorção de água (IAA), índice de solubilidade em água (ISA) e propriedades de pasta (RVA) de grãos integrais e decorticados. Os resultados da pesquisa mostraram que o tempo ótimo de cocção (OTC) dos grãos integrais e decorticados de milheto foram de 30 min e 20 min, respectivamente. O OH não promoveu mais rápida cocção dos grãos. A decorticação impactou mais nos atributos de qualidade que o método de aquecimento aplicado. No Capítulo III , os grãos integrais de milheto foram submetidos a cinco processamentos: decorticação (10 min), cocção em panela aberta (98 ºC/ 30 min), cocção por aquecimento ôhmico (98 ºC/30 min/ 60Hz), germinação (30 ºC/48 h) e extrusão (140ºC/600 rpm/parafuso duplo), sendo posteriormente transformados em farinhas. Foram avaliadas a composição nutricional (proteínas, lipídeos, fibra alimentar, minerais) e as propriedades funcionais (distribuição de tamanho de partículas, densidade absoluta, ISA, IAA, RVA). Os resultados mostraram que a farinha crua de milheto possui, em média em base úmida, 62,5% de carboidratos, 12,0% de proteína, 5,6% de lipídios, 8,2% de fibra alimentar e, os minerais como potássio, fósforo e magnésio são os que possuem em maior concentração. Os resultados mostraram que a farinhas processadas são nutritivas e que a decorticação impactou significativamente na redução nutricional deste alimento. Farinhas cruas integrais e decorticadas possuíram elevada viscosidade, podendo ser úteis para elaboração de mingaus. Farinhas germinadas e extrusadas apresentaram grandes vantagens nutricionais (retenção de proteínas e fibras alimentares) e tecnológicas (como alta solubilidade, reduzida viscosidade), sendo ingredientes potenciais para uso em bebidas e alimentos congelados. Farinhas cozidas por ambos métodos apresentaram mesmo teor nutricional que a farinha crua e apresentaram elevada capacidade de absorção de água, sendo ingredientes potenciais para elaboração de quibes sem glúten ou produtos panificáveis. No geral, os grãos de milheto, processados ou não, são considerados alimentos nutritivos e que, dependendo do processo utilizado, podem ter variadas aplicações no desenvolvimento de produtos.

Palavras-chave: cereal, glúten, extrusão, aquecimento ôhmico.

ABSTRACT

DIAS-MARTINS, Amanda Mattos . **Effects of different processing on the nutritional and functional quality of millet grains (*Pennisetum glaucum* (L). R. Br.), RJ.** 2019. 105p. Thesis, (Ph.D in Food Science and Technology). Institute of Technology, Department of Food Technology, Federal Rural University of Rio de Janeiro, Seropédica, RJ, 2019.

Millet is the sixth most produced cereal in the world. In Brazil, although this crop is adapted to our agricultural conditions with about 5 million hectares planted, its production is destined only for animal feed and for plant cover (no-tillage). One reason for non-human consumption is possibly related to a lack of knowledge about the nutritional benefits and product types that can be made with the grain. Thus, the objective of this work was to promote knowledge about the technological and nutritional potential of millet grains (*Pennisetum glaucum* L.R.Br) to human consumption in Brazil and to evaluate the effects of different processing on the chemical, physical and nutritional properties of this cereal. The thesis was subdivided into three chapters, in Chapter I, an extensive bibliographical review was elaborated on millet grains in relation to food safety, nutritional composition, technological processes, health benefits and grain based products. In Chapter II, the effects of two methods of cooking, ohmic heating (OH) (emergent method) and open pan (conventional method) on yield, texture (TPA), color (C *, h °, ΔE), water absorption index (IAA), water solubility index (ISA) and pulp (RVA) properties of whole grains and decorticates. The results of the research showed that the optimal cooking time (OTC) of the whole grains and decorticated millet were 30 min and 20 min, respectively. OH did not promote faster grain cooking. Decortication impacted more on quality attributes than the applied heating method. In Chapter III, whole millet grains were submitted to five processing: decortication (10 min), cooking in open pan (98 ºC / 30 min), heating by oven heating (98 ºC / 30 min / 60 Hz), germination (30 ºC / 48 h) and extrusion (140 ºC / 600 rpm / double screw), and then processed into flours. The nutritional composition (proteins, lipids, dietary fiber, minerals) and functional properties (particle size distribution, absolute density, ISA, IAA, RVA) were evaluated. The results showed that crude millet flour has, on average in wet basis, 62.5% carbohydrates, 12.0% protein, 5.6% lipids, 8.2% dietary fiber, and minerals such as potassium, phosphorus and magnesium are the ones with the highest concentration. The results showed that the processed flours are nutritious and that decortication had a significant impact on the nutritional reduction of this food. Whole and decorticated raw flours have high viscosity and may be useful for making porridges. Germinated and extruded flours presented great nutritional advantages (retention of proteins and food fibers) and technological (such as high solubility, low viscosity), being potential ingredients for use in frozen foods and beverages. Flours cooked by both methods presented the same nutritional content as the raw flour and presented a high capacity of water absorption, being potential ingredients for the elaboration of gluten-free kibbeh or bread products. In general, millet grains, processed or unprocessed, can be considered as nutritious foods and depending on the process applied, may have varied applications in the development of products.

Keywords: cereal, gluten, extrusion, ohmic heating.

SUMÁRIO

INTRODUÇÃO GERAL

Grãos de cereais são as maiores fontes energéticas utilizadas por humanos e por isso, possuem um papel importante na dieta alimentar. Entretanto, mudanças climáticas e a escassez de água podem vir futuramente, impactar na disponibilidade de algumas culturas de cereais no Brasil e no mundo (AL-AMIN & AHMED, 2016; KHANAL & MISHRA, 2017). Com isso, pesquisadores tem buscado estudar fontes alternativas de alimentos que possam tanto se adaptar as novas condições climáticas, quanto suprir as necessidades nutricionais da população.

Neste contexto, o *millet,* termo genérico que descreve grãos pequenos pertencentes à família *Poaceae*, pode ser uma cultura alternativa, que exibe características fisiológicas vantajosas quando comparado a outros cereais, tais como a alta resistência ao calor, ao déficit hídrico e a baixa fertilidade do solo (TAYLOR, 2016). Estas características se devem ao extenso sistema radicular da planta, que permite uma eficaz extração de água e nutrientes de camadas mais profundas do solo. Existem diferentes espécies de *millets,* sendo a mais produzida a *Pennisetum glaucum* L. R. Br., popularmente conhecida como *pearl millet*, milheto ou milheto–pérola, devido seus grãos terem formato perolado. Grãos de milheto são cereais nutritivos e possuem características nutricionais relevantes como, teor de proteínas e fibra alimentar superior ao arroz, conteúdo lipídico semelhante ao milho, teor de aminoácidos essenciais (leucina, isoleucina e lisina) superior ao trigo e propriedades funcionais como baixo índice glicêmico em função das características do amido, teor de compostos fenólicos e ácidos graxos.(ANNOR, TYL, MARCONE, RAGAEE & MARTI, 2017).

Grãos de milheto podem ser consumidos cozidos de forma integral ou polida, germinados, extrudados, fermentados ou mesmo, em forma de farinha como ingrediente para produção de variados alimentos. Além disso, podem ser usados como uma alternativa de alimento viável para celíacos, pessoas sensíveis ao glúten ou adeptos ao estilo alimentar , pois não possuem as proteínas formadoras do glúten, tendo como vantagem o custo inferior aos grãos de milho (DIAS MARTINS, 2018).

No Brasil, sementes de milheto são cultivadas há mais de 50 anos, contudo, apenas destinadas principalmente para sistema de plantio direto (cobertura de solo) e alimentação animal. A Embrapa Milho e Sorgo vem conduzindo programas de melhoramento genético de sementes de milheto desenvolvendo novas cultivares como a BRS1502, com o objetivo de melhorar e divulgar os potenciais usos da cultura na agricultura brasileira. Em parceria com

Embrapa Agroindústria de Alimentos, os pesquisadores vem buscando avaliar possíveis formas para inserir os grãos de milheto na alimentação humana brasileira.

Para que os grãos de *Pennisetum glaucum* (L). R. Br. possam se tornar uma alternativa viável para diversificação alimentar dos brasileiros, é necessário estudar os tipos de processamentos que podem ser aplicados aos grãos e os produtos que podem ser elaborados. Com base na tecnologia de processamento de outros grãos há propostas de processamento para milheto, tais como decorticação, germinação, extrusão e cocção.

A decorticação é um processo que pode promover remoção parcial ou total do pericarpo e germe do cereal. Contudo, dependendo do método usado para decorticação (mecânico ou manual), umidade do cereal e tempo de decorticação, diferentes propriedades físicas e nutricionais podem ser obtidas (HAMA *et al.,* 2011). Já a cocção de cereais consiste em imergir os grãos em uma panela aberta com água em ebulição até obtenção de textura macia e modificação de coloração. Contudo, dependendo de alguns fatores como, tamanho dos grãos, umidade, teor de água, e tempo de cocção, variações nutricionais e funcionais podem ser obtidas.

O processo de germinação de grãos de milheto é realizado em três etapas: imersão em água, germinação sob condições de temperatura e umidade controladas e secagem (TAYLOR, 2016). Contudo, em função da atividade metabólica necessária para crescimento do embrião, pode ocorrer tanto perdas ou aumento de alguns nutrientes no produto final. As características nutricionais e funcionais do produto final podem sofrer variações pois são influenciadas por fatores extrínsecos e intrínsecos do alimento.

A extrusão termoplástica é um processamento térmico sob alta temperatura e curto tempo (HTST) utilizado para produzir diferentes produtos como cereais matinais, *snacks* e farinhas instantâneas. Entretanto, a qualidade nutricional e funcional de um extrudado é dependente diretamente do tipo da matéria-prima utilizada e variáveis do processo como a temperatura, tipo de parafuso e velocidade de rotação do parafuso (VARGAS-SOLÓRZANO *et al*., 2014). Desta forma, dependendo da intensidade do tratamento térmico, modificações físicas e nutricionais podem ser ocasionadas.

O aquecimento ôhmico é um tratamento emergente que tem sido reportado como promissor para cocção de cereais como milho e arroz (GAVAHIAN *et al.,* 2019) . É definido como um processo onde a corrente elétrica passa diretamente pelo alimento promovendo seu aquecimento. Dentre as vantagens da tecnologia está o rápido e homogêneo aquecimento. Contudo, diferentes propriedades nutricionais e físicas podem ser obtidas dependendo da matriz alimentar , do campo elétrico e da condutividade elétrica utilizadas.

Assim, após revisão , observou-se que não há estudos no Brasil que avaliem os efeitos desses processamentos nas propriedades nutricionais e funcionais dos grãos de milheto. Além disso, não há nenhum estudo em bases internacionais e nacionais que relate o uso de tecnologias emergentes como aquecimento ôhmico em grãos de milheto. Neste contexto, este trabalho teve como objetivo submeter grãos de milheto a cinco diferentes processamentos a avaliar seus efeitos nas características nutricionais como, teor de macro e micronutrientes e, nas características funcionais como, cor, textura, viscosidade, densidade e solubilidade e absorção em água.

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CAPÍTULO I

POTENTIAL USE OF PEARL MILLET (*Pennisetum glaucum* (L.) R. Br.) IN BRAZIL: FOOD SECURITY, PROCESSING, HEALTH BENEFITS AND NUTRITIONAL PRODUCTS

POTENTIAL USE OF PEARL MILLET (*PENNISETUM GLAUCUM* (L.) R. BR.) IN BRAZIL: FOOD SECURITY, PROCESSING, HEALTH BENEFITS AND NUTRITIONAL PRODUCTS

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Review

Potential use of pearl millet (*Pennisetum glaucum* (L.) R. Br.) in Brazil: Food security, processing, health benefits and nutritional products

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ABSTRACT

Climate change can cause an increase in arid soils, warmer weather, and reduce water availability, which in turn can directly affect food security. This increases food prices and reduces the availability of food. Therefore, knowledge concerning the nutritional and technological potential of non-traditional crops and their resistance to heat and drought is very interesting. Pearl millet is known to produce small nutritious cereal grains, which can endure both heat and dry conditions, and is one of the basic cereals of several African and Asian countries. Although this species has been cultivated in Brazil for at least 50 years it is only used as a cover crop and animal feed, but not for human consumption. Nonetheless, pearl millet grains have a high potential as food for humans because they are gluten-free, higher in dietary fiber content than rice, similar in lipid content to maize and higher content of essential amino acids (leucine, isoleucine and lysine) than other traditional cereals, such as wheat and rye. In addition, the crop is low cost and less susceptible to contamination by aflatoxins compared to corn, for example. Most grains, including pearl millet, can be milled, decorticated, germinated, fermented, cooked and extruded to obtain products such as flours, biscuits, snacks, pasta and non-dairy probiotic beverages. Pearl millet also has functional properties; it has a low glycemic index and therefore it can be used as an alternative food for weight control and to reduce the risk of chronic diseases, such as diabetes. Thus, this review intends to show the potential of pearl millet as an alternative food security crop, particularly in countries, like Brazil, where it is not commonly consumed. Also this review presents different processes and products that have been already reported in the literature in order to introduce the great potential of this important small grain to producers and consumers.

Keywords: Gluten-Free; Cereals; Whole grains; Flour; Functional Foods

1 INTRODUCTION

Cereals have been consumed by humans for thousands of years, and they play an important role in our diet as the main source of energy. World cereal production has been increasing by about 1 billion tonnes over the last 50 years; in 2016, production was 29% greater than 2013 (FAOSTAT, 2017). In this scenario, Brazil is the world's sixth largest cereal producer (about 3% of world production), an average of 85 million tonnes in 2016. In that year, the most produced cereal in Brazil were maize (76%), rice (13%), wheat (8%) and sorghum (1%) (FAOSTAT, 2017).

The agricultural production is one of the most vulnerable sectors to climate change (ALEXANDRATOS & BRUINSMA, 2012). Also, increase in global temperatures, global water deficit, contamination by mycotoxins associated with increasing world population (estimated in 9 billion by 2050) will be responsible for substantial reduction of crop yields resulting in price increase and major food security concerns (AL-AMIN & AHMED, 2016; KHANAL & MISHRA, 2017). Thus, questions about which crops should be considered to overcome those negative effects are major challenges facing the agribusiness (DARYANTO, WANG, & JACINTHE, 2016).

In this context, pearl millet may be an alternative crop that exhibits great advantageous physiological characteristics when compared to other cereals as it is resistant to drought, low soil fertility, high salinity and high temperature tolerance (RAI, GOWDA, REDDY, & SEHGAL, 2008). These characteristics are due to its extensive root system, which allows effective water and nutrients extraction from deeper soil layers (NETTO & DURÃES, 2005). In addition for being a non-trangenic crop (DUNWELL, 2014), millet has a low incidence of mycotoxin contamination compared to other crops, such as wheat and maize (BANDYOPADHYAY, KUMAR, & LESLIE, 2007; KUMAR *et al.,* 2008; JURJEVIC, WILSON, WILSON, & CASPER, 2007; WARE *et al*., 2017; WILSON *et al.,* 2006).

Millet, which is a generic term that includes various small grain species belonging to the Poaceae family of grasses, has been a food source for humans for more than 10,000 years (LU *et al.,* 2005; LU *et al.,* 2009). In 2016, millet stood out as the sixth most produced cereal in the world (28 million tonnes) (FAOSTAT, 2017). However, it is classified as a subsistence crop, and approximately 90% of world production is destined for human consumption in poor regions of Africa and Asia (COUNCIL, 1996). One of the major impediment that has restrained the increase of millet production is the scarce economic and technological support provided (MACAULEY & RAMADJITA, 2015). This can be clearly evidenced by observing the world average productivity from the last fifty years, where this crop continues to present the lowest average yield (0.8 tonnes ha-1) when compared to other crops of same botanical family, such as maize (4.0 tonnes ha-1), rice (3.8 tonnes ha-1); wheat (2.6 tonnes ha-1); barley (2.5 tonnes ha-1); rye (2.3 tonnes ha-1); oats (2.1 tonnes ha-1) and sorghum (1.5 tonnes ha-1) (FAOSTAT, 2017b). On the other hand, low productivity is the result of a lack of investment on research genetic programs associated with low use of agronomical techniques, such us fertilizers and mechanization (MACAULEY & RAMADJITA, 2015).

The millet species have different physiological characteristics compared to other cereal crops as they are resistant to drought, low soil fertility, high salinity and high temperatures. These characteristics are due to the extensive root system of these grasses, which allows extraction of water and nutrients from deeper soil layers (DEVI, VIJAYABHARATHI, SATHYABAMA, MALLESHI, & PRIYADARISINI, 2014).

There are several common names of millets: Pearl millet (*Pennisetum glaucum* (L.) R. Br., *Pennisetum typhoides* auct. non (Burm.) Stapf & C.E. Hubbard., *Pennisetum americanum* (L.) Leeke, *Pennisetum spicatum* (L.) Körn), Finger Millet (*Eleusine coracana* (L.) Gaertn), Kodo millet (*Paspalum scrobiculatum* L.), Little millet (*Panicum sumatrense* Roth ex Roem. & Schult), Proso Millet (*Panicum miliaceum* (L.), Foxtail millet (*Setaria italica* (L.) P. Beauv.), Barnyard millet Japanese, (*Echinochloa esculenta* (A. Braun) H. Scholz, *Echinochloa frumentacea* L.; *Echinochloa utilis* Ohwi & Yab.), Browntop millet (*Urochloa ramosa* (L.) Nguyen, *Brachiaria ramosum* (L.) Stapf); Sawa millet (*Echinochloa colona* (L.) Link), White fonio (*Digitaria exilis* (Kippist) Stapf) and Black fonio (*Digitaria iburua* Stapf) (FAO, 1995; USDA, 2016). The Food and Agriculture Organization, FAOSTAT, does not distinguish the production of the different millet species, except pearl millet (*pennisetum glaucum* (L.) R. Br.) which is the most produced specie; however, in China, foxtail millet is the most relevant (TAYLOR, 2016).

Pearl millet grains can be processed and consumed as ingredients in diversified foods. They are called "nutri-cereals" because of their high protein, fiber, mineral, and fatty acids contents, as well as their antioxidant properties. Also they are an alternative food for celiacs and gluten sensitive individuals (ANNOR, MARCONE, CORREDIG, BERTOFT, & SEETHARAMAN, 2015; CHANDRASEKARA, NACZK, & SHAHIDI, 2012; RONA *et al*., 2007; SALEH *et al.,* 2013). Furthermore, the chemical composition of millet grains can promote various health benefits such as reduction of oxidative stress among others (ISLAM, MANNA, & REDDY, 2015; NANI *et al.,* 2015)

Despite its nutritional potential, pearl millet is only used for cereal tillage (vegetable cover for mulch) and feed (grain and forage) in Brazil (NETTO & DURÃES, 2005). The total tillage area in Brazil is around 32 million hectares, and pearl millet (*Pennisetum glaucum* (L.) R. Br.) is one of the main cover crops in the Cerrado and the Southern region, in systems of rotation for important commodities, such as soy, maize and cotton (FEBRAPDP, 2012; FEBRAPDP, 2017; NETTO & DURÃES, 2005). Although, millet is not consumed by man in Brazil, this cereal could be considered as an alternative food for human consumption because of its availability, nutritional aspects and also as a source gluten-free food. Thus, this review aims to emphasize the important nutritional and technological potential of pearl millet grains for human consumption, by awakening food industries and consumers to its benefits especial for celiacs and diabetic individuals due to its low glycemic index.

2 PEARL MILLET GRAINS

Pearl millet is an erect grass that has a summer annual cycle of between 75 and 120 days depending on environmental conditions. Usually, it is of fast growth and reaches an average height of 1.5 to 3 m (**Fig.1**). The plant develops compact cylindrical panicles that are 2 to 3 cm wide and 15 to 60 cm long capable of producing between 500 and 2000 seeds per panicle (DURÃES, MAGALHÃES, & DOS SANTOS, 2003; TAYLOR, 2016). Its seeds are oval shaped, similar to a pearl, from which it gets its name. The grains are 3 to 4 mm long, and they are significantly larger than other millet species such as: proso, finger, foxtail, kodo and little millet. In general, 1000 seeds of the pearl millet species have an average weight of 8 g, almost three times the weight of proso millet (DURÃES *et al.,* 2003; FAO, 1995).

Figure 1: Pearl millet (*Pennisetum glaucum* (L.) R. Br. cultivar BRS1502)

This species *Pennisetum glaucum* (L.) R. Br. has many different names around the world. In southern Brazil it is known as *milheto-pérola*, *capim-charuto* and *pasto-italiano,* in the United States, *pearl millet*, *bulrush millet*, *cattail millet*, while in Europe it is called *candle millet* and *dark millet*. In France, it is known as *mil du Soudanou petit mil*, and in Spain and Arabic countries: *mijo perla* and *duhun*, respectively. In addition, in African countries, *P. glaucum* is known as *massago* (Angola), *dagusa* (Etiópia, língua Amharic), *mhunga* (Zimbábue), *gero* (Nigéria, língua Hausa), *hegni* (Niger, língua Djerma), *mahangu, sayo* (Mali), *dukhon* (Sudão). In India, it is better known as *bajra, bajrou, sajje* (Taylor, 2016).

3 USES OF PEARL MILLET IN BRAZIL

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) was first introduced to Brazil in 1929 and since then, it has been adapted to the South, Southeast and Center-West regions of the country (BURTON, 1972; KILL, 2005).

Since the 1960s, the research program on *P. glaucum* in Brazil, has focused on improving the agronomic characterization of cultivars that can be used for different purposes, such as: soil cover for no-tillage systems, forage plant, silage or as grains for animal feed (CAMPELO, TEIXEIRA NETO, & DA ROCHA, 1998; GUIMARÃES JUNIOR, GONÇALVES, & RODRIGUES, 2009; SANTOS *et al.,* 2017).

The practice of no-tillage is used to increase agricultural productivity and to control soil erosion, while at the same time it reduces compaction and improves nutrient availability in the soil (CAMPELO *et al*., 1998). Pearl millet has a fast growth rate, a deep root system and a good production of green mass. The no-tillage system uses plant residues from decomposed straw as a soil cover improving the productivity of commodities such as soy and cotton, due to a reduction of soil temperatures, a slow release of nutrients and improved water retention in the soil (NETTO & DURÃES, 2005). Although, there is no official production data in Brazil, the estimated planted area of pearl millet (*Pennisetum glaucum* (L.) R. Br.) is 5 million ha.

In addition, factors such as nutritional composition and low production costs of pearl millet grains (half the price of maize) have motivated studies for replacing maize with pearl millet in animal feed (ALONSO *et al.* 2017, BERGAMASCHINE *et al*., 2011). According to Rodrigues *et al*., (2001), the substitution of maize for pearl millet in animal feed may have advantages, such as higher protein content, lower incidence of mycotoxins and similar lipid content.

4 NUTRITIONAL QUALITY OF PEARL MILLET GRAINS

In recent years, there has been an increase of products based on whole grains because they contain a higher content of dietary fiber, micronutrients and bioactive compounds (GONG *et al.,* 2018). Pearl millet grains can be considered a possible alternative for food diversification because they have the fibers, minerals, proteins and antioxidants with similar or even higher levels than those found in traditional grains such as rice and maize (SALDIVAR, 2003, TAYLOR, 2016). The chemical composition of pearl millet along with other traditional cereal crops is given in **Table 1**. The chemical composition of pearl millet (dry basis) is, on average, 72.2% carbohydrate, 11.8% protein, 6.4% lipid, 7.8% dietary fiber and 1.8% minerals (**Table 1**). However, variations of these levels are possible due to genotype, climatic conditions, soil nutrient content and type of processing.

4.1 Carbohydrates

Carbohydrates are the main components of cereals and are mostly starch, followed by fibers. The average content of carbohydrates in pearl millet grains was 72.2%, which is lower than rice (84.9%), maize (78.1%) and higher than wheat (68.8%) (**Table 1**). The average dietary fiber content in pearl millet grains was 7.8% (**Table 1**). This value was higher than rice (3.5%) although, similar to maize (8.1%). On the other hand, it has lower fiber content when compared to rye (16.8%), barley (14.5%) and oats (11.8%) (**Table 1**). Consumption of food sources with fiber should be stimulated as they promote quality of life (CHUANG *et al*., 2012), reduce symptoms of depression (MIKI *et al*., 2016), reduce incidences of inflammatory bowel diseases (LIU, WU, LI, & ZHANG, 2015) and heart problems (KIM & JE, 2016).

4.2 Proteins and amino acids

Proteins are the second major component in pearl millet grains. The grains contain 11.8% protein, similar to sorghum (10.7%) and higher than maize (9.2%) and rice (8.6%) (**Table 1**). However, pearl millet has a lower protein content compared to oats (16.7%), wheat (14.0%) and rye (13%) (Table 1). Oscillations in the protein content of cereals are observed in different research projects, because they are directly related to factors such as: genotypic characteristics, soil moisture content and use of nitrogen fertilizers (FAO, 1995).

Table 1 Nutritional composition of cereals [a]

Proximate composition (g/100 g)	Pearl millet	Maize	Wheat	Sorghum	Rye	Barley	Rice	Oat
Carbohydrate	69.4 – 76.1 (72.2)	69.4 – 85.1 (78.1)	67.7 – 69.3 (68.8)	72.2 – 77.1 (74.6)	64.7 – 67.7 (66.4)	63.4 – 73.3 (68.2)	81.9 – 88,2 (84.9)	60.6 – 62.9 (61.4)
Protein	9.7 – 14.5 (11.8)	7.7 – 12.1 (9.2)	13.2 – 14.8 (14.0)	9.4 – 11.8 (10.7)	11.6 – 14.0 (13.0)	11.5 – 15.3 (12.9)	6.7 – 11.0 (8.6)	14.9 – 17.1 (16.7)
Lipid	5.1 – 9.5 (6.4)	1.9 – 4.3 (3.3)	1.5 – 2.8 (2.2)	3.2 – 3.7 (3.4)	1.8 – 2.0 (1.9)	1.8 – 2.7 (2.2)	1.6 – 2.2 (2.1)	6.4 – 8.6 (7.6)
Dietary Fiber	7.0 – 8.5 [b] (7.8)	4.5 – 8.2 (8.1)	11.9 – 15.1 (13.1)	7.3 – 11.8 (9.6)	16.1 – 17.4 (16.8)	11.5 – 16.7 (14.5)	2.7 – 4.7 (3.5)	11.2 – 12.5 (11.8)
Ash	0.8 – 2.5 (1.8)	0.7 – 1.8 (1.3)	1.8 – 2.0 (1.9)	1.5 – 1.8 (1.7)	1.7 – 2.0 (1.9)	1.5 – 2.9 (2.2)	0.6 – 1.4 (0.9)	1.4 – 3.6 (2.5)

[a] All values are expressed on dry matter basis. The lower number indicates the average value and upper refers to the range of values.

[b] Range of Dietary fiber from the following sources: Saldivar, 2003 and Taylor, 2016.

The other data correspond to the range found in the following sources, for pearl millet: Gull, Prasad, & Kumar, 2015; Obadina et al., 2016; Saldivar, 2003; Siroha, Sandhu, & Kaur, 2016 and Taylor, 2016. For the other cereals: Butt, Tahir-Nadeem, Khan, Shabir, & Butt, 2008; Prasad, Hymavathi, Babu, & Longvah, 2018; Saldivar, 2003; TACO, 2011; TBCA, 2017; USDA, 2016.

The composition of amino acids of pearl millet compared to other traditional cereal crops is shown in **Table 2**. Pearl millet protein amino acid composition has on average high levels of glutamic acid (23 g/100 g protein), but lower than wheat and barley. Glutamic acid is a nonessential amino acid known to be a neurotransmitter or precursor of γ-aminobutyric acid (GABA) (HAN, KIM, YANG, JEONG, & KIM, 2015). Foods rich in glutamic acid may prove to be beneficial to health and according to HAN *et al.* (2015) glutamic acid supplementation may be considered an alternative therapy to reduce the symptoms of menopause, as it (glutamic acid) may attenuate the estrogen deficiency at this period; Furthermore, GABA is associated to several physiological, nutritional and food ingredient functions (SHARMA, SAXENA, & RIAR, 2017).

Moreover, pearl millet has higher content of essential amino acids (leucine (10.7 g/100 g protein) and isoleucine (4.4 g/100 g protein)) than wheat, rice and oats. However, it is the cereal that has the lowest concentration of methionine (1.1 g/100 g protein) (**Table 2**).

According to FAO (1995) the quality of protein in pearl millet grains satisfies the nutritional requirements of an adult, but does not meet the protein needs of infants and children, due to the amount of essential amino acids, especially lysine, which is usually low in cereals. Nevertheless, the lysine content of pearl millet (3.1 g/100 g protein) is relatively higher than maize, rye, wheat and sorghum (**Table 2**). This is possibly a consequence of the large germ of pearl millet with a relatively high proportion of albumin and lysine-rich globulins (TAYLOR, 2016).

4.3 Fats

Pearl millet grain has high lipid content because the germ represents ~ 21% of the whole grain (TAYLOR & EMMAMBUX, 2008). However, the high lipid content of this species may promote negative effects on the stability of products such as flours, because unsaturated fatty acids are susceptible to oxidation (TIWARI, JHA, PAL, SETHI, & KRISHAN, 2014). On the other hand, the presence of unsaturated fatty acids may be beneficial. According to Annor et al. (2015), the composition of fatty acids (quantification and type) present in each species of millet is directly related to the hypoglycemic properties of this cereal. According to Taylor (2016) and Annor et al. (2015) the major fatty acids of pearl millet grain are linoleic acid (C18:2), typically 39-45%; oleic acid (C18:1), 21–27%; and palmitic acid (C16:0), 20–21%.

Table 2 Amino acid composition of cereal grains [a]

Amino acids (g/100 g protein)	**Pearl millet [a]**	**Maize**	**Wheat**	**Sorghum**	**Rye**	**Barley**	**Rice**	**Oat**
Leucine	10.7	12.3	6.8	12.9	5.4	6.8	8.2	7.6
Isoleucine	4.4	3.6	3.3	3.7	2.0	3.6	4.1	4.1
Valine	4.9	5.1	4.3	4.6	3.0	4.9	5.8	5.5
Threonine	4.0	3.8	2.8	3.7	2.8	3.4	3.5	3.4
Arginine	4.6	4.9	4.9	3.9	4.4	5.0	8.7	7.1
Lysine	3.1	2.8	2.7	2.1	2.8	3.7	3.5	4.1
Methionine	1.1	2.1	1.7	1.7	1.5	1.9	2.4	1.8
Cisteine	1.5	1.8	2.0	1.9	na	2.0	1.8	2.4
Tryptophan	1.4	0.7	1.3	1.2	1.0	1.7	1.2	1.4
Glutamic Acid	23.0	18.8	32.8	20.6	22.2	26.1	18.4	21.9
Alanine	8.7	7.5	3.7	8.9	3.9	3.9	5.6	5.2
Proline	5.8	8.7	15.7	7.7	7.8	11.9	4.7	5.5
Aspartic Acid	8.5	6.9	5.5	6.6	5.4	6.2	9.2	8.6
Phenylalanine	4.4	4.9	5.2	5.2	4.2	5.6	5.3	5.3
Tyrosine	3.0	4.1	2.1	2.7	1.9	2.9	5.3	3.4
Histidine	2.3	3.0	2.7	1.9	1.8	2.2	2.5	2.4
Glycine	2.7	4.1	4.3	3.7	4.0	3.6	4.5	4.9
Serine	5.2	4.7	4.7	4.9	4.4	4.2	5.2	4.4

[a] Range of values data from: Adebiyi, Obadina, Adebo, & Kayitesi, 2017; Osman, 2011; Saldivar, 2003; Taylor, 2016.

Other cereals source: USDA (2016). na= no analyzed.

The lipid content of pearl millet grains is very high (6.4%), almost twice the amount in sorghum (3.4%) and maize (3.3%), but lower than oats (7.6%) (**Table 1**). However, variations can be found and result in different comparisons to that observed above; for example Belton & Taylor (2002) found that some pearl millet cultivars have lower lipid contents than maize.

4.4 Minerals

The total ash content of pearl millet (1.8%) is similar to wheat (1.9%), higher than maize (1.3%) and rice (0.9%) and lower than oats (2.5%) and barley (2.2%). Regarding mineral composition, phosphorus (~3.338 mg/kg dry basis), potassium (~3.932 mg/kg dry basis) and magnesium (~1.333 mg/kg dry basis) are found in considerable quantities, while minerals such as calcium (~300 mg/kg dry basis), iron (~ 18 mg/kg dry basis) and zinc (~43 mg/kg dry basis) are in much lower quantities (RAGAEE, ABDEL-AAL, & NOAMAN, 2006; SALDIVAR, 2003; TAYLOR, 2016). Due to the low content of zinc and iron, some research programs have concentrated efforts on promoting biofortification of peal millet (ULLAH *et al.,* 2016).

4.5 Bioactive compounds

Studies have demonstrated that whole grain millet and its bran are rich sources of phenolic compounds (phenolic acids and flavonoids) and a source of natural antioxidants (CHANDRASEKARA & SHAHIDI, 2011a, 2011b, 2011c; CHANDRASEKARA *et al.,* 2012). According to the above mentioned works, these compounds, which are secondary products of plant metabolism, have antioxidant capacities and are associated to reduced risk of chronic diseases related to oxidative stress. Pearl millet grains have low concentrations of benzoic acid derivatives (hydroxybenzoic acid, gallic acid, p-hydroxybenzoic, vanillic, syringic and protocatechuic), but high levels of cinnamic acid derivatives (hydroxycinnamic, coumaric, ferulic, sinapic) (CHANDRASEKARA & SHAHIDI, 2011A; TAYLOR, & DUODU, 2015). Nani *et al.,* (2015) reported that pearl millet contained gallic acid (15.3 μg/g), syringic acid (7.4 μg/g g/g), p-coumaric (1350 μg/g) and ferulic acid (199μg/g).

When comparing the quantities of phenolic acids with other cereals, N'Dri et al. (2013) found that pearl millet presented higher amounts (64.8 mg/kg) of phenolic acids than sorghum (27.3 mg/kg). Dykes & Rooney (2007) observed that pearl millet had 1,478 μg/g, which was higher than that found in rye (1,366 μg/g), barley (1,346 μg/g), wheat (1,342 μg/g), sorghum (746 μg/g), maize (601 μg/g) and oats (472 μg/g). Among the phenolic acids, ferulic and p-coumaric acids are predominant in pearl millet grains, according to Chandrasekara & Shahidi (2011b) and N'dri et al. (2013). In general, phenolics are not distributed evenly in the grain, these compounds are mainly found in the pericarp so the most beneficial form to consume pearl millet is as whole grain or bran (CHANDRASEKARA & SHAHIDI, 2011b).

When comparing the antioxidant capacity of five whole grains, wheat (*Triticum aestivum* L.), pearl millet (*Pennisetum glaucum* (L.) R. Br.), rice (*Oryza sativa*), maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L. Moench), Prajapati, Patel, Parekh & Subhash (2013) found that pearl millet grains had the most phenolic compounds and the highest antioxidant activity. According to Nani et al. (2015) phenolic compounds found in whole grains have immunosuppressive effects and can be used as dietary supplements for the treatment of autoimmune diseases.

4.6 Antinutritional factors

The main antinutritional compounds found in pearl millet are phytic acid and C-glycosylflavones, such as apigenin, glucosylvitexin, glucosylorientin and vitexin (TAYLOR, 2016). Phytic acid is a natural antioxidant present in most cereals that inhibits oxidation reactions of the seeds and retains inorganic phosphorus when consumed. However, from the nutritional point of view, high consumption of these compounds may lead to a reduction in the bioavailability of minerals, such as zinc, calcium and manganese, due to the chelating capacity of bivalent minerals (GUPTA, GANGOLIYA, & SINGH, 2015). In addition, the presence of phytic acid in cereals may promote the reduction of protein digestibility by inhibiting the action of protease enzymes in the digestive tract. According to García-Estepa, Guerra-Hernández, & García-Villanova, (1999) the phytic acid content of millet grains resembles cereals such as maize and sorghum, and is higher than oats, rice, barley, rye and wheat. According to various authors, pearl millet levels of phytic acid can vary from 588 mg/100 g to 1382 mg/100 g (EL HAG, EL TINAY, & YOUSIF, 2002; GABAZA, SHUMOY, MUCHUWETI, VANDAMME, & RAES, 2017).

Flavones are a subclass of flavonoids belonging to phenolic compounds that are synthesized by the plant through the stimulus of light and responsible for the yellow pigmentation of P. glaucum (REICHERT, 1979). Although, luteolin, a flavone present in millets, have antioxidant properties, other studies have shown evidence that the presence of C-glycosylflavones in foods may promote the inhibition of thyroid peroxidase (TPO), an enzyme produced in the thyroid gland responsible for the production of thyroid hormones (GAINTAN *et al.,*1989a; MEZZOMO & NADAL, 2016).

Gaitan *et al.,(*1989a),(1989b) evaluated the anti-thyroid and goitrogenic effect of pearl millet grains. They observed that rats fed *Pennisetum glaucum* (L.) R. Br. meal showed a significant reduction in thyroid hormone production, suggesting that high concentrations of C-glycosylflavones (1020 mg/kg) in particular, glucosylvitexin, glucosylorientin and vitexin were responsible for the result. However, due to scarce studies, it is still unclear how much intake is necessary to promote similar effects in humans. Thus, it is suggested that, grains of pearl millet are submitted to processing promoting the reduction of antinutritional factors for the safe consumption of the grain (BRAHMBHATT, FEARNLEY, BRAHMBHATT, EASTMAN, & BOYAGES, 2001).

5 GRAIN PROCESSING AND EFFECTS

The post-harvest millet process starts with the separation of the grains from the panicle, removal of soils, such as stones and sands followed by debranning. Wholemeal products do not require debranning. Subsequently the grains can be submitted to different secondary processes, such as physical (milling, decortication, cooking, roasting, blanching, extrusion and popping), chemical (acid treatment) and biological processes (fermentation, germination), for elaboration of diversified food products. **Table 3** shows the effects of these processes commonly applied to millet grains, as well as their respective effects.

Grain cooking, milling and decortication, are the most common processes used on millet, because they are simple and inexpensive, that can be applied as pre-treatment. Pearl millet grains (whole or decorticated) can be cooked similarly to “rice” either by open-pan boiling or pressure cooking and even in microwave oven (TAYLOR, BARRION, & ROONEY, 2010). Milling is used to produce pearl millet flours with different particle size distribution, but it causes the release of fatty acids present in the germ prone to oxidation hence reducing flour shelf-life (TIWARI *et al.,* 2014). Decortication can be used to obtained light colored grains with better palatability, taste and texture. It promotes changes in grain color by removing the bran, which in turn reduces flavonoids content up to 50%. The flavonoids are responsible for the grayish pigmentation (AKINGBALA, 1991). However, due pearl millet germ is embedded in the endosperm, decortication is not effective and more efforts are still needed to develop techniques to remove the pericarp and germ without causing significant reduction of grain endosperm (HAMA *et al.,* 2011).

Table 3 Effect of processing on pearl millets

Process	Processing effects	References
Cooking	Reduction of antinutritional factors	Jha, Krishnan, & Meera (2015)
	Reduction of antioxidant capacity	Chandrasekara *et al.* (2012); N'Dri *et al.* (2013)
	Reduction of phenolic compounds	Hithamani & Srinivasan (2014)
	Increase of antioxidant capacity	Prajapati, Patel, Parekh, & Subhash (2013)
	Increase of zinc bioaccessibility	Jha, Krishnan, & Meera (2015)
Milling	Reduction of flour shelf life	Bhati, Bhatnagar, & Acharya (2016)
	Increase of free fatty acid content	Tiwari, Jha, Pal, Sethi, & Krishan. (2014)
Decortication	Reduction of antioxidant potential	Chandrasekara, Naczk, & Shahidi (2012), Chandrasekara & Shahidi (2011b)
	Reduction of fiber, iron and zinc content	Hama *et al*. (2011)
	Reduction of phytic acid content and phenolic compounds	Chandrasekara *et al.* (2012); Hama *et al.* (2011)
	Reduction of insoluble fiber, amino acids and lipids Increase of starch and protein digestibility	Serna-Saldivar, Clegg, & Rooney (1994)
Roasting	Reduction of essential amino acids content	Obadina *et al.* (2016)
	Reduction of phytic acid content and free fatty acids	Jalgaonkar, Jha, & Sharma (2016)
	Increase of bioaccessibility of phenolics Increase of phenolic acid content	Hithamani & Srinivasan (2014)
Acid treatment	Reduction of c-glycosylflavones and grain color modification	Reichert (1979)
	Reduction of free fatty acid content Increase of iron bioavailability	Bhati *et al.* (2016)
Blanching	Reduction of free fatty acid content	Bhati et al. (2016); Kadlag, Chavan, & Kachare (1995)
	Reduction of the rancidity	Nantanga, Seetharaman, de Kock, & Taylor, 2008

	Increase of flour shelf life	Nantanga *et al.,* 2008; Kadlag, Chavan, & Kachare (1995)
	Increase of iron availability *in vitro*	Bhati *et al,*. (2016)
Extrusion	Reduction of antioxidant capacity	N'Dri *et al.,* (2013)
	Reduction of antinutritional factors	Balasubramanian, Kaur, & Singh (2014); Sihag et al. (2015)
	Increase of protein digestibility	Almeida-Dominguez et al. (1993)
	Increase of solubility and cold paste viscosity	
Popping	Increase of starch digestibility *in vitro*	Muralikrishna, Malleshi, Desikachar, & Tharanathan (1986)
	Reduction of grain density	Singh & Sehgal (2008)
Germination	Reduction of phenolic compounds	Nithy, Ramachandramurty,& Krishnamoorthy (2007).
	Reduction of antinutritional factors	Badau, Nkama, & Jideani (2005); Sihag et al., (2015); Tou et al., 2006
	Increase of protein digestibility	Nkama, Gbenyi, & Hamaker (2015)
	Increase of free amino acid content	Elyas, El Tinay, Yousif, & Elsheikh (2002)
	Increase all the essential amino acids content	Adebiyi, Obadina, Adebo, & Kayitesi, 2017
	Increase of mineral composition	
	Increase of solubility	Akinola, Badejo, Osundahunsi,& Edema (2017)
Fermentation	Increase of product acidity,	Khetarpaul & Chauhan (1990a), (1990b)
	Reduction of phytic acid	Elyas *et al.,* (2002); Gabaza et al. (2017); Twari et al (2014a.b);
	Reduction of phenolic compounds	Elyas *et al,*. (2002)
	Reduction of minerals (Na, K, Mg, Cu, Fe, Mn and Zn)	Tiwari *et al*. (2014)
	Increase of bioactive compounds content	Salar, Purewal, & Sandhu (2017), Gabaza et al. (2017)
	Increase of protein digestibility	Ali, El Tinay, & Abdalla (2003)
	Increase of mineral composition and amino acid content	Adebiyi *et al., (*2017)
	Increase of paste viscosity properties	Akinola *et al.,* (2017)

Roasting, acid and blanching treatments are applied to pearl millet grains to modify their color, to reduce antinutritional factors and to promote the inactivation of lipases, that are responsible for the rancid odor when grain is milled, thus product shelf life is improved (BHATI *et al.,* 2016). In the roasting process, grains or flours are exposed to heat in the dry condition, where temperatures may vary from 120 to 180 °C for 75 to 120 min. Acid treatment requires the preparation of various types of acid solutions, such as acetic acid, tartaric acid or diluted HCl, whereas in blanching, the grains are immersed in water at ~ 100 °C for 10 to 90 s.

Extrusion cooking and popping are thermo-physical processes still to be explored with great potential to be introduced given the commercial opportunity. Extrusion requires considerable investment, which may restrict its use. Apart from economic issue, extrusion of pearl millet grain presents certain challenges, due to its high concentration of lipids and fibers. However, some authors have reported that pearl millet has great potential to be used to develop extruded products with better digestibility and also improved sensory acceptance (BALASUBRAMANIAN, KAUR, & SINGH, 2014). Unlike extrusion, popping is a simple and inexpensive technique, but few studies have been reported this process (**Table 3**). A possible explanation is due to grain characteristics, since its grain has a fine pericarp and farinaceous endosperm, factors that do not contribute to a good expansion performance (HADIMANI, MURALIKRISHNA, THARANATHAN & MALLESHI, 2001, MISHRA, JOSHI, & PANDA, 2014). Nevertheless, this disadvantage could be a motivation for promoting research programs to improve pearl millet germplasm aiming to improve grain the expansion properties and diversified pearl millet genotypes (KUMARI *et al*., 2015).

Biologycal processes, like germination and fermentation are household practice commonly in African and Asia countries which promotes physicochemical alterations (**Table 3**). In general, the germination process is carried out in three stages: immersion in water (~ 8 h), germination (24 - 28 ºC/ 24 - 48 h) and drying (~50 °C) (Taylor, 2016). The fermentation is carried out by immersing the grains in water at room temperature from 2 to 4 days. The grain fermentation can be accomplished either by the addition of starter cultures, which improves process control and standardization of the final product or by spontaneous fermentation via natural microbiota, like lactic bacteria (*Lactobacillus fermentum*, *Lactobacillus plantarum* and *Pediococus pentosaceus*), yeast (*Saccharomyces cerevisiae*, *Candida kruse*) and/or molds (*Mucor circinelloides*, *Rhizopus microsporus*) (FRANZ *et al.,* 2014).

In addition, emerging technologies such as irradiation can be also applied to pearl millet grains, but scarce studies have been reported in the literature. According to Mohamed, Ali, Ahmed, Ahmed & Babiker (2010) irradiation up to 2 kGy can be applied to pearl millet meal, as an alternative to thermal and chemical treatments to increase shelf-life and to reduce the incidence of the bitter taste during flour storage. Even lower exposure of 0.5 kGy radiation promotes significant reduction of fungal growth and phytic acid content.

Due to the fact that millet is not a commercial and popular grain worldwide, the application of other emerging technologies, such as ohmic heating, pulsed electric field, cold plasma and microwave have not been reported in the literature yet. It is envisaged the use of these techniques in millet grains may be promising, as these techniques have been studied with other cereals with potential of being commercially used (ALTAN, 2014; MÉNERA-LÓPEZ *et al*., 2013; QIAN, GU, JIANG, & CHEN, 2014; THIRUMDAS *et al*., 2016).

6 HEALTH PROMOTING PROPERTIES

Pearl millet grains have several functional properties, due to their high fiber content, fatty acid composition and phytochemical compounds (Annor et al., 2015; Patel, 2015). In addition to its anti-inflammatory, antihypertensive, anticarcinogenic characteristics, and the presence of antioxidant compounds, pearl millet also helps to reduce the risk of heart diseases, inflammatory bowel disease and atherosclerosis (CHANDRASEKARA & SHAHIDI, 2011A, 2011B; ROMIER, SCHNEIDER, LARONDELLE, & DURING, 2009).

Pearl millet grains are naturally gluten-free, an advantage considering that the intake of gluten protein, particularly found in wheat, may promote several metabolic disorders in certain individuals, causing allergies, intolerances, autoimmune diseases and intestinal permeability (CZAJA-BULSA, 2015; HOLLON *et al.,* 2015). Therefore, pearl millet may prove to be a low-cost functional alternative for celiacs, people with non-celiac gluten sensitivity (NCGS), gluten sensitivity patients (GS) and food style adepts. The acquired knowledge of peal millet health benefits is of great importance that should be considered in nutritional programs.

6.1 Hypoglycemic Properties

According to the World Health Organization (WHO) type 2 diabetes has increased in children and adults worldwide, and is now the 6th cause of death in the world (WHO, 2017a).

In Brazil, this disease affects 9 million people, and is classified as the 4th largest cause of death in the country (PORTAL BRASIL SAÚDE, 2015; WHO & UNPARTNERS, 2015).

In general, diabetes can be triggered due to genetic pre-dispositions, obesity and high consumption of foods with a high glycemic index. According to Nani, Brixi-Gormat, Bendimred-Hmimed, Benammar, & Belarbi (2012) and Ugare, Chimmad, Naik, Bharati, & Itagi (2014) the use of millet grains to develop new products can help prevent the risk of diabetes, due to their low glycemic levels.

Nani et al. (2012) evaluated the effect of the consumption of pearl millet (*Pennisetum glaucum* (L.). R. Br.) on the glucose metabolism of diabetic rats. The authors concluded that the consumption of pearl millet meal may be useful to correct hyperglycemia caused by type 2 diabetes, and therefore reduce the intensity of the disease, that can be an alternative to prevention. Hegde, Rajasekaran, & Chandra (2005) observed that animals consuming a feed with 55% kodo millet meal resulted in a reduction of 42% hyperglycemia, 27% of cholesterol and increased levels of enzymatic antioxidants (GSH, vitamin E and C) and non-enzymatic (glutathione reductase).

According to Annor, Tyl, Marcone, Ragaee & Marti, (2017), millet grains have higher slowly digestible starch than other cereals, which was atributed to starch characteristics, such as, amylose content , granular structure (polygonal format with porous surfaces), amount and type of fatty acids (oleic acid content) capable of forming complexes with starch molecules, the starch-protein-lipid interactions and high content of fibers. Furthermore, the presence of phytochemicals (phenolic acids, flavonoids and phytates) may contribute to inhibit the action of gastrointestinal α -amylase (pancreatic) and α-glycosidase (intestinal) enzymes that hydrolyze starch, oligosaccharides and disaccharides to monosaccharides, thus reducing body hyperglycemia (CAO & CHEN, 2012; KIM, HYUN, & KIM, 2011; SHOBANA, SREERAMA, & MALLESHI, 2009; SHUKLA & SRIVASTAVA, 2014). However, the hypoglycemic nature of millets can be significantly affected by the type of processing applied to them, hence the adoption of processes that maintain low starch hydrolysis should be encouraged (ANNOR *et al*.,2017).

6.2 Anticancer properties

Cancer is the second largest cause of global death, with around 8.8 million deaths in 2015. The types of cancers that kill most are: lung (1.69 million); liver (788,000); colorectal (774,000); stomach (754,000) and breast (571,000 deaths) (WHO, 2017b). Although the disease is related to different factors such as genetic predisposition; smoking, obesity, chronic inflammation, age, immunosuppression and radiation, research shows that the choice of food that is consumed during life may also influence the predisposition to develop this disease (NATIONAL CANCER INSTITUTE, 2015).

Countries such as India, Burkano Faso and Nigeria where the base diet is small cereal grains, mainly millet, there is a low incidence of cancer compared to countries that are based on cereals such as corn and wheat (CHEN, COLE, MI, & XING, 1993; VAN RENSBURG, 1981; WHO & UNPARTNERS, 2015). Some medical studies have suggested that peptides, proteins and phenolic acids found in millet grains may be promising in the prevention and treatment of cancer (SHAN *et al,.* 2014; SHAN *et al.,* 2015; SRIKANTH & CHEN, 2016).

According to Chandrasekara & Shahidi (2011a) phenolic acids such as ferulic and p-coumaric, found in whole pearl millet (*Pennisetum glaucum* (L.) R. Br.), have the capacity to reduce HT29 tumor cells. Nishizawa et al. (2002) reported a reduction in the proliferation of hepatic inflammatory cells in rats fed a 20% protein proso millet diet (*Panicum miliaceum* L). In a similar research, Zhang, Liu, & Niu (2014) observed that proso millet grains also have antiproliferative activity in vitro against human liver cancer cells. Shan et al. (2014) and Shan et al. (2015) found that millet bran-derived peroxidase from foxtail millet (*Setaria italica*), has a potential therapeutic use to treat rectal colon cancer, due to its strong inhibitory power on preventing cancer cells from growing in in vitro and in vivo tests.

However, grain functionality is directly linked to the type of processing applied to it. According to Chandrasekara & Shahidi (2011a) decorticated pearl millet grains have lower anticarcinogenic activity than whole grains. Sharma, Saxena, & Riar (2016) observed that germinated grains of barnyard millet (*Echinochloa frumentaceae*) are more functional because they have a higher phenolic acid content and gamma-amino butyric acid (GABA), an amino acid that promotes health benefits such as mood enhancement and inhibition of developing cancer cells.

6.3 Probiotic and prebiotic properties

Prebiotics are non-digestible food ingredients that when consumed promote growth and maintenance of probiotics, microorganisms belonging to intestinal microflora, which are related to health benefits of the host (FAROOQ, MOHSIN, LIU, & ZHANG, 2013). The consumption of foods that contain prebiotics and probiotics is recommended in order to promote the improvement of the immune and physiological systems, as well as the reduction of inflammatory bowel diseases, antimicrobial action and reduction of allergic diseases (BENÍTEZ-PÁEZ *et al.,* 2016; SANDHU *et al*., 2017). The potential of fibers as prebiotic and the probiotic strains of fermented pearl millet have also been studied (PALANISWAMY & GOVINDASWAMY, 2016; PEDERSEN, OWUSU-KWARTENG, THORSEN, & JESPERSEN, 2012).

According to Farooq et al. (2013), fibers in pearl millet grains have a prebiotic effect in vitro, resulting in the growth of probiotic cultures such as *Lactobacillus rhamnosus* and *Bifidobacterium bifidus*. The authors also observed enhancement of short chain fatty acids (SCFA), metabolic products of fermentation, known to regulate physiological processes. They suggested that millet dietary fiber has a potential for being used in formulation of new nutraceuticals.

In relation of probiotic strains isolated from fermented millet products, Pedersen et al. (2012) identified potential probiotic yeasts (*Trichosporon asahii*) in Fura, a spontaneously fermented product made from pearl millet grains. Owusu-Kwarteng, Tano-Debrah, Akabanda, & Jespersen (2015) reported that *Lactobacillus fermentum* strains isolated from fermented pearl millet grains presented antimicrobial activity against *Listeria monocytogenes* and Staphylococcus aureus. In other research, Nduti et al. (2016) isolated strains of *Lactobacillus* in Kimere, a fermented millet-based food, that was inoculated in yoghurts and distributed to needy children in Kenya. The authors observed that the consumption of 200 mL for 7 days of the probiotic yogurt promoted reduction of aflatoxin intoxication.

7 FOODS AND BEVERAGES PRODUCTS OF PEARL MILLET

In Africa and India, millet pearl grains are used to produce a wide variety of traditional local foods, such as porridges, flatbreads, couscous, sweets, alcoholic beverages (opaque beer or Dogon millet beer, chibuku shake, mbeg, merissa) and non-alcoholic drink (pombe, pito, boza, kunun Zaki, bushera, mahewu, oskikundu, marewa) (ADEBIYI, OBADINA, ADEBO, & KAYITESI, 2016). Most of these products are produced in household or in small production units consumed in the main meals. However, few studies have been reported the nutritional and sensory aspects of these products. In addition, due to the vast number of different local variations, this research will be limited on describing few examples of food preparations available in international literature with pearl millet, that are displayed in **Table 4**.

Fura, a short shelf-life made in ball format (**Fig. 2a**) obtained from cooking a mixture of fermented and non-fermented pearl millet flour and spices is widely consumed in Nigeria (ADEBIYI, OBADINA, ADEBO, & KAYITESI, 2016). Depending on the region, it is consumed with yoghurt ("*nono*") or mashed in water before consumption as porridge (FILLI, NKAMA, JIDEANI, & IBOK, 2013).

Porridges (*ben-saalga, uji, ugali, oko, tõ, obushera, koko, bogobe, tchobal, bouillie* and *kambu koozh*) may be prepared from pearl millet flour as fermented or unfermented food product, being the major consumed pearl millet food product (**Fig.2b**) (ADEBIYI, OBADINA, ADEBO, & KAYITESI, 2016). Their consistency range between thick and thin, depending on the concentration of flour (30% down to 10%). Different types of porridges may be prepared by cooking flour in boiling water accompanied by vigorous stirring. In addition, these products can vary greatly in flavor and pH depending on the added ingredient (tamarind extract, lemon juice or potash) (KAJUNA, 2001; TAYLOR, 2016).

Figure 2: Traditional local foods made from pearl millet. a) Fura, Nigeria; b) Porridge, Nigeria; c) *Ladoo*, India

Flatbreads are very popular pancake-like gluten-free products that can be made with unfermented pearl millet flour with warm water, like to *Chapati*, *Rotti* or *Rotla*, typical of India (SIROHA, SANDHU, & KAUR, 2016) or, with fermented pearl millet flour like, *Lohoh*, from Saudi Arabia (OSMAN, 2011). These flatbreads can be cooked on hot plate (tawa) or clay griddle or wood fire stove and served at meals, depending on the region, with hot pickle (India) or spicy sauces (Sudam) (**Fig.3**). Couscous is a staple food of the North African cuisines and also known as semolina. However, in Senegal and Mali, couscous (*karaw; thiakri, thiacry*) is traditionally made from flour or decorticated pearl millet grains. This couscous is popularly consumed with vegetables or yoghurt (TAYLOR, BARRION, & ROONEY, 2010).

In addition to salted products, pearl millet grains can be used to produce sweets. Ladoo and Dakuwa prepared small sweet balls (**Fig.2c**) from roasted pearl millet grain flours that are typically consumed in India and Nigeria, respectively. According to Singh & Sehgal (2008) and Nkama, Gbenyi, & Hamaker (2015) potential ingredients such as popped pearl millet grain and malted flour can be added to those sweets for nutritional improvements (**Table 4**).

Furthermore, pearl millet flour has great potential for developing popular products in other parts of the globe such as ready-to-eat snacks (BALASUBRAMANIAN *et al.,* 2012), weaning products (BALASUBRAMANIAN *et al.,* 2014) and non-dairy fermented beverages (MRIDULA & SHARMA, 2015). Moreover, it can be used as an alternative wheat flour substitute in different food preparations, like biscuits, pastas, whole meal breads and kibbeh (ADEBIYI, OBADINA, ADEBO, & KAYITESI, 2016; AWOLU, 2017; BRASIL, CAPITANI, TAKEUCHI, & FERREIRA , 2015; JALGAONKAR & JHA, 2016; MAKTOUF *et al.,* 2016).

Figure 3: Flatbread (*chapati)* made with pearl millet flour in India. a) flour-water mixture is kneaded to obtain a cohesive dough; b) cooked *chapati* in clay griddle; c) prepared dish of chapati in India.

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Table 4 Products made with pearl millet

Product	Country	Ingredients	Main Conclusions	Reference
*Fura balls**	Nigeria	Extruded pearl millet-soybean flours blends, black pepper and ginger	-The extrusion of the millet-soybean blends promoted increase of shelf-life and increase in protein content of the product; -The maximum proportion of soybean meal added should be 38.5% for sensorial acceptance.	Filli, Nkama, Jideani, & Ibok (2013)
Ben-saalga (porridge)*	Burkina Faso	Pearl millet flour, groundnuts, malted barley flour, sugar, ginger and mint.	-The addition of the groundnuts and malted barley flour, enabled a porridge with the appropriate balance of macronutrients and high energy density at a suitable consistency.	Tou *et al.* (2007)
Chapati (flatbread)*	India	Pearl millet flour and water	-Chapatti making resulted in decrease of antioxidant properties, when compared to its raw flour.	Siroha, Sandhu, & Kaur (2016)
Ladoo (sweet)*	India	Popped pearl millet, roasted and dehusked groundnut, roasted and dehusked chickpea, jaggery and water	-Popped pearl millet can be successfully used for the preparation of *ladoo*, reducing cost and increasing *in vitro* protein digestibility.	Singh & Sehgal (2008)
Dakuwa (sweet)*	Nigeria	Malted pearl millet flour, groundnut, ginger, hot pepper and honey	-The malting of grains improved the apparent protein digestibility without affecting the sensorial aspects such as texture and taste.	Nkama, Gbenyi, & Hamaker (2015)
Ready-to-eat snack	India	Whole pearl millet, finger millet and decorticated soy bean blended extruded	-The pearl millet expanded in a twin screw extruder, presented a light color, and promising characteristics for the production of low cost extrudates.	Balasubramanian, Singh, Patil & Onkar (2012)
Weaning food	India	Malted and extruded millet flour (MEMF), extruded millet flour (EPMF), extruded barley flour (EBF), malted and extruded barley flour (MEBF), skim milk powder (WPC), sugar and vegetable oil (VO)	-The mixture that resulted in the best physical and sensorial characteristics was EBF (20.99%), EPMF (20.77%), MEFE (7.39%), MEBF(6.53%), WPC (5%), sugar (6%) and vegetable oil (4 mL); -The use of pearl millet and barley showed great potential for replacing rice and wheat, including at a low cost and with a highly nutritious product.	*Balasubramanian et al. (2014)*

Non-dairy Probiotic Beverage	India	Germinated pearl millet, wheat, barley flour; oat meal, guar gum, sugar cardamom and probiotic culture (*Lactobacillus acidophilus* NCDC14) in 50:50 soy/H_20.	-There was a linear increase in probiotic count with an increase in pearl millet flour in the beverage; -The authors suggested that in order to obtain better sensory acceptance the addition of pearl millet flour should be limited to 4 g/ 100 mL.	Mridula & Sharma (2015)
Biscuits	South Africa	Fermented or raw whole millet flours, defatted soy flour, sugar, margarine and water	-The pearl millet biscuits are nutritious, resembling the texture of commercial wheat cream crackers, but they differ in their pronounced flavor; - The authors suggested that the consumption of these biscuits has the potential of being a supplementary food for school-age children in Africa.	Omoba, Taylor, & Kock (2015)
	Nigeria	Germinated and fermented pearl millet flours, sugar, sunflower oil, vanilla extract, yeast and water	- The use of germinated and fermented flours results in higher nutritional quality and lower bulk density; -Sprouted and fermented pearl millet flour are potential ingredients for baking products.	Adebiyi,Obadina,Mulaba-Bafubiandi, Adebo, & Kayitesi (2016)
Pastas	India	Durum wheat semolina (DWS), pearl millet flour (PMF), finger millet flour (FMF) and carrot pomace powder (CPP)	- The pearl millet pasta showed greater loss of solids, reduction of weight gain and firmness, but presented a higher nutritional value; - Desirable physical characteristics of pasta was obtained with 46% DWS, 30% PMF, 20% FMF and 4% CPP.	Gull *et al.,* (2014)
	India	Depigmented pearl millet flour, chickpea flour and water.	- The authors suggested depigmentation of pearl millet grains by acid treatment or bleaching, in order to obtain clearer pasta that improves its acceptability.	Rathi, Kawata, & Sehgal (2004)
	India	Pearl millet flour (PMF) and wheat semolina (WS).	- PMF increased the protein content significantly, however the hardness, cohesion and elasticity decreased; - WS: PMF (70:30) was good for making pasta with desirable quality.	Jalgaonkar & Jha (2016)
Breads	Nigeria	Pearl millet flour (PMF), kidney beans, tigernut and xanthan gum	- Composite flour with 85% of PMF is a viable alternative to 100% wheat flour replacement in bread production.	Awolu (2017)
	India	Wheat flour, pearl millet flour, yeast, sodium chloride and water	- The results showed that pearl millet flour had excellent emulsifying properties;- Addition of 5 % of pearl millet flour is able to improve the rheological properties of the dough, as well as the specific volume and texture of the bread.	Maktouf *et al.,* (2016)

Kibbeh gluten free	Brazil	Mixed meat, pearl millet flour roasted, soybean oil, salt, fresh mint; fresh parsley and fresh garlic.	- The kibbeh showed good acceptability not differing significantly from whole wheat flour samples for overall appearance, texture and taste; - Pearl millet flour can be used as a substitute for wheat flour for formulations intended for the celiac public because of their nutritional quality, sensorial and stability after freezing.	Brasil,Capitani,Takeuchi, & Ferreira (2015)

(*) = traditional local foods of pearl millet

8 CONCLUSIONS

Based on the information presented, pearl millet grains have great potential as food, due to some relevant nutritional characteristics like: high protein content, dietary fibers and minerals, besides it is considered a low cost crop. In addition, millet has great relevance for guaranteeing food safety, due to the agronomic characteristics of the crop, such as resistance to high temperatures and low rainfall requirements, also the grains have a low incidence of mycotoxins and it is not a transgenic crop.

Furthermore varied types of savory and sweet nutrient products can be made with pearl millet grains and their flours as typical dishes consumed in Africa and India as well as popular products such as biscuits, extrudates, pastas, gluten-free kibbeh and non-dairy probiotic drinks.

Thus, greater incentive on genetic improvement in order to launch new cultivars of high grain yield are needed and evaluate the potential use and benefits of pearl millet in food should be made, because this cereal has significant relevance for food safety as well as being a viable alternative for consumers seeking low priced, nutritious and sustainable food products.

9 FUTURE PERSPECTIVE AND CHALLENGES TO STIMULATE THE CONSUMPTION OF MILLET AS FOOD IN BRAZIL

Despite the fact that Brazil has the third largest number of international publications on agronomic aspects of pearl millet (search based on Scopus® abstract and citation database), studies on the potential use of this cereal as food are still scarce in this country. Based on the present review, it seems clear that pearl millet is a viable cereal alternative for Brazilians consumers and also for export if millet consumption demand increases worldwide. As vast Brazilian agricultural lands are currently planted with pearl miller, it is reasonable to say that millet grain production is an agronomic activity to be economically explored. Furthermore, as pearl millet in Brazil has been mainly adopted by the agrobusiness in consortium with known commodities such as maize and soybean, it should be encouraged the production of millet in poor Brazilian lands, particularly in the semi-arid region of the Northeast. In this region, the variability of rainfalls is the primary factor that affects food security, therefore the knowledge of using millet in this region, together with the adequacy of agricultural policies, could expand the options of profitable and nutritious food for both farmers and animal feeding.

In addition, due to the trend towards the development of products with heath and sustainability appeal, pearl millet has great potential to be used as raw material for food preparation of industrial products. Despite the use of pearl millet for food is promising, there are still few drawbacks that need to be overcome, as examples, there is a lack of specific cultivars designed for grain production adapted to different regions and the knowledge of the potential use of millet in the Brazilian diet.

The implementation of public policies that would encourage the cultivation of millet for grain production and, the support of research institutions to promote advanced studies on the development of food products are few examples of great challenges to consolidate the use of millet in Brazil.

In this scenario, as strategies for insertion of millet in Brazilian food, Embrapa (Brazilian Agriculture Research Corporation) has carried out preliminary studies on the chemical composition of the pearl millet (*Pennisetum glaucum* (L.) R. Br., cultivar BRS1502), and development of products based on this cereal, as presented in Fig.4. However, future studies should still be performed to better understand the potential of all pearl millet cultivars produced in the country and also improvement programs of new cultivars suitable for grain production of interesting for food nutrition. These studies should consider the evaluation of nutritional and antinutritional aspects of the grains, as well as studies on the effects of different processes for food use; development of diversified products and sensory assessment; grain and flour lipid stability; clinical essays considering Brazilian diets where hypoglycemic and goitrogenic effects would be studied.

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10 REFERENCES

ADEBIYI, J., OBADINA, A., ADEBO, O., & KAYITESI, E. Fermented and malted millet products in Africa: Expedition from traditional/ethnic foods to industrial value added products. **Critical reviews in Food Science and nutritio**n (just-accepted), 00-00. (2016).

ADEBIYI, J. A., OBADINA, A. O., ADEBO, O. A., & KAYITESI, E. Comparison of nutritional quality and sensory acceptability of biscuits obtained from native, fermented, and malted pearl millet (*Pennisetum glaucum*) flour. **Food Chemistry**, 232(Supplement C), 210-217, 2017.

ADEBIYI, J. A., OBADINA, A. O., MULABA-BAFUBIANDI, A. F., ADEBO, O. A., & KAYITESI, E. Effect of fermentation and malting on the microstructure and selected physicochemical properties of pearl millet (*Pennisetum glaucum*) flour and biscuit. **Journal of Cereal Science**, 70, 132-139, 2016

AKINGBALA, J. Effect of processing on flavonoids in millet (Pennisetum americanum) flour. **Cereal Chemistry** (USA), 1991.

AKINOLA, S. A., BADEJO, A. A., OSUNDAHUNSI, O. F., & EDEMA, M. O. Effect of preprocessing techniques on pearl millet flour and changes in technological properties. **International Journal of Food Science and Technolog**y, 52(4), 992-999, 2017.

AL-AMIN, A. Q., & AHMED, F. Food Security Challenge of Climate Change: **An Analysis for Policy Selection. Futures,** 83, 50-63, 2016

ALEXANDRATOS, N., & BRUINSMA, J. **World agriculture towards 2030/2050**: the 2012 revision(no. 12-03). (pp.32,80) Rome, FAO: ESA Working paper, 2012

Ali, M. A., El Tinay, A. H., & Abdalla, A. H. (2003). Effect of fermentation on the in vitro protein digestibility of pearl millet. **Food Chemistry**, 80(1), 51-54., 2003.

ALMEIDA-DOMINGUEZ, H., GOMEZ, M., SERNA-SALDIVAR, S., WANISKA, R., ROONEY, L., & LUSAS, E. Extrusion cooking of pearl millet for production of millet-cowpea weaning foods. **Cereal Chemistry**, 70(2), 214-219, 1993.

ALONSO, M. P., DE MORAES, E. H. B. K., PEREIRA, D. H., DOS SANTOS PINA, D., MOMBACH, M. A., HOFFMANN, A., . . . SANSON, R. M. M. Pearl millet grain for beef cattle in crop-livestock integration system: Intake and digestibility. **Semina:Ciencias Agrarias**, 38(3), 1461-1472, 2017.

ALTAN, A. Effects of pretreatments and moisture content on microstructure and physical properties of microwave expanded hull-less barley. **Food Research International**, 56(Supplement C), 126-135, 2014.

ANNOR, G. A., TYL, C., MARCONE, M., RAGAEE, S., & MARTI, A. Why do millets have slower starch and protein digestibility than other cereals? **Trends in Food Science & Technology,** 66(Supplement C), 73-83, 2017.

ANNOR, G. A., MARCONE, M., CORREDIG, M., BERTOFT, E., & SEETHARAMAN, K.. Effects of the amount and type of fatty acids present in millets on their in vitro starch digestibility and expected glycemic index (eGI). **Journal of Cereal Sci**ence, 64, 76-81, 2015.

AWOLU, O. O. Optimization of the functional characteristics, pasting and rheological properties of pearl millet-based composite flour. **Heliyon,** 3(2), e00240, 2017.

BADAU, M. H., NKAMA, I., & JIDEANI, I. A. Phytic acid content and hydrochloric acid extractability of minerals in pearl millet as affected by germination time and cultivar. **Food Chemistry**, 92(3), 425-435, 2005.

BALASUBRAMANIAN, S., KAUR, J., & SINGH, D. Optimization of weaning mix based on malted and extruded pearl millet and barley. **Journal of Food Science and Technology,** 51(4), 682-690, 2014.

BALASUBRAMANIAN, S., SINGH, K., PATIL, R., & ONKAR, K. K.. Quality evaluation of millet-soy blended extrudates formulated through linear programming. **Journal of Food Science and Technology**, 49(4), 450-458, 2012.

BANDYOPADHYAY, R., KUMAR, M., & LESLIE, J. F.. Relative severity of aflatoxin contamination of cereal crops in West Africa. **Food Additives and Contami**nants, 24(10), 1109-1114, 2007.

BASTOS, A. O., FILHO, L. D. C. L., PASSIPIERI, M., & BASTOS, J. F. P. Diferentes Níveis de Grão de Milheto (*Pennisetum glaucum* (L.) R. Brown) na Alimentação de Suínos1, 2**.** **Revista. Brasileira de Zootecnia**, 31(4), 1753-1760, 2002.

BELTON, P. S., & TAYLOR, J. R. (EDS.). Pseudocereals and less common cereals: grain properties and utilization potential. **Springer Science & Business** Media. 2002.

BENÍTEZ-PÁEZ, A., DEL PULGAR, E. M. G., KJØLBÆK, L., BRAHE, L. K., ASTRUP, A., LARSEN, L., & SANZ, Y.. Impact of dietary fiber and fat on gut microbiota re-modeling and metabolic health. **Trends in Food Science & Technolo**gy, 57, 201-212, 2016.

BERGAMASCHINE, A. F., FREITAS, R. V. L., VALÉRIO FILHO, W. V., BASTOS, J. F. P., MELLO, S. Q. S., & CAMPOS, Z. R.. Substituição do milho e farelo de algodão pelo milheto no concentrado da dieta de novilhos em confinamento. **Revista Brasileira de Zootecnia**, 40(1), 154-159, 2011.

BHATI, D., BHATNAGAR, V., & ACHARYA, V.. Effect of pre-milling processing techniques on pearl millet grains with special reference to in-vitro iron availability. **Asian Journal of Dairy and Food Research**, 35(1), 76-80, 2016.

BRAHMBHATT, S. R., FEARNLEY, R., BRAHMBHATT, R. M., EASTMAN, C. J., & BOYAGES, S. C.. Study of biochemical prevalence indicators for the assessment of iodine deficiency disorders in adults at field conditions in Gujarat (India). **Asia Pacific Journal of Clinical Nutrition,** 10(1), 51-57, 2001.

Brasil, T. A., Capitani, C. D., Takeuchi, K. P., & Ferreira, T. A. P. d. C.. Physical, chemical and sensory properties of gluten-free kibbeh formulated with millet flour (*Pennisetum glaucum* (L.) R. Br.). **Food Science and Technology** (Campinas), 35(2), 361-367, 2015.

BURTON, G. W.. Registration of Tiflate Pearl Millet (Reg. No. 25). **Crop Science**, 12(1), 128-128, 1972.

BUTT, M. S., TAHIR-NADEEM, M., KHAN, M. K. I., SHABIR, R., & BUTT, M. S.. Oat: unique among the cereals. **European Journal of Nutrition**, 47(2), 68-79, 2008.

Campelo, G. D. A., Teixeira Neto, M. L., & da Rocha, C. M. C. (1998). Validação de plantio direto de soja sobre residuo de milheto. **Embrapa Meio-Norte-Documentos,** 1998.

CAO, H., & CHEN, X.. Structures required of flavonoids for inhibiting digestive enzymes. Anti-Cancer Agents in Medicinal Chemistry (**Formerly Current Medicinal Chemistry-Anti-Cancer Agents**), 12(8), 929-939, 2012.

CHANDRASEKARA, A., NACZK, M., & SHAHIDI, F.. Effect of processing on the antioxidant activity of millet grains. **Food Chemistr**y, 133(1), 1-9, 2012.

CHANDRASEKARA, A., & SHAHIDI, F.. Antiproliferative potential and DNA scission inhibitory activity of phenolics from whole millet grains**. Journal of Functional Foods**, 3(3), 159-170, 2011a.

CHANDRASEKARA, A., & SHAHIDI, F.. Bioactivities and antiradical properties of millet grains and hulls**. Journal of Agricultural and Food Chemistry**, 59(17), 9563-9571, 2011b

CHANDRASEKARA, A., & SHAHIDI, F. Determination of antioxidant activity in free and hydrolyzed fractions of millet grains and characterization of their phenolic profiles by HPLC-DAD-ESI-MSn. **Journal of Functional F**oods, 3(3), 144-158., 2011c.

CHEN, F., COLE, P., MI, Z., & XING, L. Y. Corn and wheat-flour consumption and mortality from esophageal cancer in shanxi, China. **International journal of cancer**, 53(6), 902-906, 1993.

CHUANG, S.-C., NORAT, T., MURPHY, N., OLSEN, A., TJØNNELAND, A., OVERVAD, K., . . . KAAKS, R. . Fiber intake and total and cause-specific mortality in the European Prospective Investigation into Cancer and Nutrition cohort. **The American journal of clinical nutrition,** 96(1), 164-174. 2012.

COUNCIL, N. R.. Lost Crops of Africa: Volume I: Grains. Washington, DC: **The National Academies Press,** 1996.

CZAJA-BULSA, G.. Non coeliac gluten sensitivity–A new disease with gluten intolerance. **Clinical Nutrition**, 34(2), 189-194, 2015.

DARYANTO, S., WANG, L., & JACINTHE, P.-A. . Global Synthesis of Drought Effects on Maize and Wheat Production. **PLoS ON**E, 11(5), e0156362, 2016.

DEVI, P. B., VIJAYABHARATHI, R., SATHYABAMA, S., MALLESHI, N. G., & PRIYADARISINI, V. B. (2014). Health benefits of finger millet (*Eleusine coracana* L.) polyphenols and dietary fiber: a review. **Journal of food science and tech**nology, 51(6), 1021-1040, 2014.

DUNWELL, J. M.. Transgenic cereals: current status and future prospects. **Journal of Cereal Science**, 59(3), 419-434, 2014.

DURÃES, F. O. M., MAGALHÃES, P. C., & DOS SANTOS, F. G.. Fisiologia da planta de milheto. **Embrapa Milho e Sorg**o-Circular Técnica, 2003.

DYKES, L., & ROONEY, L.. Phenolic compounds in cereal grains and their health benefits. **Cereal foods world**, 52(3), 105-111, 2007.

EL HAG, M. E., EL TINAY, A. H., & YOUSIF, N. E.. Effect of fermentation and dehulling on starch, total polyphenols, phytic acid content and in vitro protein digestibility of pearl millet. **Food Chemistry**, 77(2), 193-196, 2002.

ELYAS, S. H., EL TINAY, A. H., YOUSIF, N. E., & ELSHEIKH, E. A.. Effect of natural fermentation on nutritive value and in vitro protein digestibility of pearl millet. **Food Chemistry**, 78(1), 75-79, 2002.

FAO.Sorghum and millets in human nutrition. **Food and Agricultural Organization of the United Nations- Agriculture and Consumer Pro**tection. 1995. http://www.fao.org/docrep/T0818e/T0818E00.htm/ Accessed: 18.06.16

FAOSTAT. **Agriculture Organization of the United Nations Statistics Division.Data–Crops-Production**. 2017. http://www.fao.org/faostat/en/#data/QC/ Accessed 21.11.16.

FAOSTAT . **Agriculture Organization of the United Nations Statistics Division.Data–Crops-Yield**, 2017b. http://www.fao.org/faostat/en/#data/QC Accessed 07.04.18

FAROOQ, U., MOHSIN, M., LIU, X., & ZHANG, H.. Enhancement of short chain fatty acid production from millet fibres by pure cultures of probiotic fermentation. **Tropical Journal of Pharmaceutical Research**, 12(2), 189-194, 2013

FEBRAPDP. Federação Brasileira de Plantio Direto e Irrigação. (2012). **Área do Sistema Plantio Direto.** 2012. http://febrapdp.org.br/area-de-pd/ Accessed: 14.09.16.

FEBRAPDP. FEDERAÇÃO BRASILEIRA DE PLANTIO DIRETO E IRRIGAÇÃO. . Sistema **Plantio Direto é o caminho para incrementar o desempenho da agricultura nacional**. 2017. http://febrapdp.org.br/noticias/252/sistema-plantio-direto-E-o-caminho-para-incrementar-o-desempenho-da-agricultura-nacional / Accessed: 02.05.17.

FILLI, K. B., NKAMA, I., JIDEANI, V. A., & IBOK, I. U.. Effect of process variables on the hydration properties and acceptability of extruded millet-soybean blends for fura manufacture. **British Food Journal**, 115(6), 884-898, 2013.

FRANZ, C. M., HUCH, M., MATHARA, J. M., ABRIOUEL, H., BENOMAR, N., REID, G., . . . HOLZAPFEL, W. H.. African fermented foods and probiotics. **International Journal of Food Microbiology**, 190, 84-96, 2014.

GABAZA, M., SHUMOY, H., MUCHUWETI, M., VANDAMME, P., & RAES, K. . Iron and zinc bioaccessibility of fermented maize, sorghum and millets from five locations in Zimbabwe. **Food Research Internation**al, 103, 361-370, 2017.

GAITAN, E., LINDSAY, R. H., REICHERT, R. D., INGBAR, S. H., COOKSEY, R. C., LEGAN, J., . . . KUBOTA, K.. Antithyroid and goitrogenic effects of millet: role of C-glycosylflavones. **The Journal of Clinical Endocrinology & Metabolism**, 68(4), 707-714, 1989a.

GAITAN, E., LINDSAY, R. H., REICHERT, R. D., INGBAR, S. H., COOKSEY, R. C., LEGAN, J., . . . KUBOTA, K.. Antithyroid and Goitrogenic Effects of Millet: Role of C-Glycosylflavones*. **The Journal of Clinical Endocrinology & Metabolism**, 68(4), 707-714, 1989b.

GARCÍA-ESTEPA, R. M., GUERRA-HERNÁNDEZ, E., & GARCÍA-VILLANOVA, B.. Phytic acid content in milled cereal products and breads. **Food Research International**, 32(3), 217-221, 1999.

GONG, L., CAO, W., CHI, H., WANG, J., ZHANG, H., LIU, J., & SUN, B.. Whole cereal grains and potential health effects: Involvement of the gut microbiota. **Food Research International**, 103, 84-102, 2018.

GUIMARÃES JUNIOR, R., GONÇALVES, L. C., & RODRIGUES, J. A. S.. Utilização do milheto para produção de silagem. **Embrapa Cerrados-Documentos**, 2009.

GULL, A., PRASAD, K., & KUMAR, P. . Effect of millet flours and carrot pomace on cooking qualities, color and texture of developed pasta. **LWT-Food Science and Tech**nology, 63(1), 470-474, 2015.

GUPTA, R. K., GANGOLIYA, S. S., & SINGH, N. K.. Reduction of phytic acid and enhancement of bioavailable micronutrients in food grains. **Journal of food science and technology**, 52(2), 676-684, 2015.

HADIMANI, N., MURALIKRISHNA, G., THARANATHAN, R., & MALLESHI, N. . Nature of carbohydrates and proteins in three pearl millet varieties varying in processing characteristics and kernel texture. **Journal of Cereal Science**, 33(1), 17-25, 2001.

HAMA, F., ICARD-VERNIÈRE, C., GUYOT, J.-P., PICQ, C., DIAWARA, B., & MOUQUET-RIVIER, C. . Changes in micro- and macronutrient composition of pearl millet and white sorghum during in field versus laboratory decortication. **Journal of Cereal Sci**ence, 54(3), 425-433, 2011.

MACAULEY, H., RAMADJITA, T.,. Cereal crops: Rice, maize, millet, sorghum, wheat. U.N.E.C.f. (Ed.), Feeding Africa, 36. **Abdou Diouf International Conference Center**, 2015.

HAN, N.-R., KIM, H.-Y., YANG, W. M., JEONG, H.-J., & KIM, H.-M.. Glutamic acid ameliorates estrogen deficiency–induced menopausal-like symptoms in ovariectomized mice. **Nutrition Research**, 35(9), 774-783, 2015.

HEGDE, P. S., RAJASEKARAN, N. S., & CHANDRA, T. . Effects of the antioxidant properties of millet species on oxidative stress and glycemic status in alloxan-induced rats. **Nutrition Research**, 25(12), 1109-1120, 2005.

HITHAMANI, G., & SRINIVASAN, K.. Effect of domestic processing on the polyphenol content and bioaccessibility in finger millet (*Eleusine coracana*) and pearl millet (*Pennisetum glaucum*). **Food chemistry,** 164, 55-62, 2014.

HOLLON, J., PUPPA, E. L., GREENWALD, B., GOLDBERG, E., GUERRERIO, A., & FASANO, A. . Effect of gliadin on permeability of intestinal biopsy explants from celiac disease patients and patients with non-celiac gluten sensitivity. **Nutrients**, 7(3), 1565-1576, 2015.

ISLAM, T., MANNA, M., & REDDY, M. K. . Glutathione Peroxidase of *Pennisetum glaucum* (PgGPx) is a functional Cd 2+ dependent peroxiredoxin that enhances tolerance against salinity and drought stress. **PloS one**, 10(11), e0143344, 2015.

JALGAONKAR, K., & JHA, S.. Influence of particle size and blend composition on quality of wheat semolina-pearl millet pasta**. Journal of Cereal Science**, 71, 239-245, 2016.

JALGAONKAR, K., JHA, S. K., & SHARMA, D. K.. Effect of thermal treatments on the storage life of pearl millet (*Pennisetum glaucum*) flour. **Indian Journal of Agricultural Sciences**, 86(6), 762-767, 2016.

JHA, N., KRISHNAN, R., & MEERA, M. . Effect of different soaking conditions on inhibitory factors and bioaccessibility of iron and zinc in pearl millet. **Journal of Cereal Science,** 66, 46-52, 2015.

JURJEVIC, Z., WILSON, J. P., WILSON, D. M., & CASPER, H. H.. Changes in fungi and mycotoxins in pearl millet under controlled storage conditions. **Mycopathologia**, 164(5), 229-239, 2007.

KADLAG, R., CHAVAN, J., & KACHARE, D.. Effects of seed treatments and storage on the changes in lipids of pearl millet meal. **Plant foods for human nutrition**, 47(4), 279-285, 1995.

KAJUNA, S. T. A. R.. MILLET: Post-harvest operations. **Food and Agricultural Organization**, 5, 1-49. 2001. http://www.fao.org/3/a-av009e.pdf / Accessed: 05.09.16

KHANAL, A. R., & MISHRA, A. K.. Enhancing food security: Food crop portfolio choice in response to climatic risk in India**. Global Food Security**, 12, 22-30, 2017.

KHETARPAUL, N., & CHAUHAN, B. . Effect of Germination and Fermentation on Available Carhohydrate content of Pearl millet. **Food Chemistry**, 38(1), 21-26, 1990a.

KHETARPAUL, N., & CHAUHAN, B. M. . Effect of Germination and Fermentation on in vitro Starch and Protein Digestibility of Pearl Millet. **Journal of Food Science**, 55(3), 883-884, 1990b.

KIILL, L. C. H. P. . Espécies vegetais exóticas com potencialidades para o semi-árido brasileiro: Brasília: Embrapa semi-árido/**Embrapa Informação Tecnológica**, 2005.

KIM, J.-S., HYUN, T. K., & KIM, M.J.. The inhibitory effects of ethanol extracts from sorghum, foxtail millet and proso millet on α-glucosidase and α-amylase activities. **Food Chemistry**, 124(4), 1647-1651, 2011.

KIM, Y., & JE, Y. Dietary fibre intake and mortality from cardiovascular disease and all cancers: A meta-analysis of prospective cohort studies. **Archives of cardiovascular diseases**, 109(1), 39-54, 2016.

KUMAR, V., BASU, M., & RAJENDRAN, T. (2008). Mycotoxin research and mycoflora in some commercially important agricultural commodities. **Crop Protection**, 27(6), 891-905, 2008.

KUMARI, J., CHAUHAN, S., JHA, S., PANDEY, S., SATYAVATHI, C. T., & DUTTA, M.. Identification of pearl millet (*Pennisetum glaucum* (L.) R. Br.) germplasm with unique popping quality in the national genebank collections of India. **The Indian Journal of Genetics and Plant Breeding**, 75(1), 2015.

LIU, X., WU, Y., LI, F., & ZHANG, D.. Dietary fiber intake reduces risk of inflammatory bowel disease: result from a meta-analysis. **Nutrition Research**, 35(9), 753-758, 2015.

LU, H., YANG, X., YE, M., LIU, K.-B., XIA, Z., REN, X., . . . LIU, T.-S.. Culinary archaeology: millet noodles in late Neolithic China**. Nature**, 437(7061), 967-968, 2005.

LU, H., ZHANG, J., LIU, K.-B., WU, N., LI, Y., ZHOU, K., . . . YANG, X.. Earliest domestication of common millet (Panicum miliaceum) in East Asia extended to 10,000 years ago. **Proceedings of the National Academy of Sciences**, 106(18), 7367-7372, 2009.

MAKTOUF, S., JEDDOU, K. B., MOULIS, C., HAJJI, H., REMAUD-SIMEON, M., & ELLOUZ-GHORBEL, R. . Evaluation of dough rheological properties and bread texture of pearl millet-wheat flour mix. **Journal of food science and technology**, 53(4), 2061-2066, 2016.

MÉNERA-LÓPEZ, I., GAYTÁN-MARTÍNEZ, M., REYES-VEGA, M., MORALES-SANCHEZ, E., & FIGUEROA, J. Physico-chemical properties and quality assessment of corn flour processed by a continuous ohmic heating system and traditional nixtamalization. **CyTA-Journal of Food,** 11(sup1), 8-14, 2013.

MEZZOMO, T. R., & NADAL, J. Efeito dos nutrientes e substâncias alimentares na função tireoidiana e no hipotireoidismo. DEMETRA: **Alimentação, Nutrição & Saúde**, 11(2), 427-443, 2016.

MIKI, T., EGUCHI, M., KUROTANI, K., KOCHI, T., KUWAHARA, K., ITO, R., . . . MIZOUE, T.. Dietary fiber intake and depressive symptoms in Japanese employees: The Furukawa Nutrition and Health Study. **Nutrition**, 32(5), 584-589, 2016.

MISHRA, G., JOSHI, D., & PANDA, B. K. . Popping and puffing of cereal grains: a review. **J. grain processing storage**, 1(2), 34-46, 2014.

MOHAMED, E. A., ALI, N. A., AHMED, S. H., AHMED, I. A. M., & BABIKER, E. E. . Effect of radiation process on antinutrients and HCl extractability of calcium, phosphorus and iron during processing and storage. **Radiation Physics and Chemistry,** 79(7), 791-796, 2010.

MRIDULA, D., SHARMA, M., & GUPTA, R.. Development of quick cooking multi-grain dalia utilizing sprouted grains. **Journal of food science and technology**, 52(9), 5826-5833, 2015.

MURALIKRISHNA, G., MALLESHI, N., DESIKACHAR, H., & THARANATHAN, R.. Effect of popping on the properties of some millet starches. **Starch-Stärke,** 38(2), 48-51, 1986.

N'DRI, D., MAZZEO, T., ZAUPA, M., FERRACANE, R., FOGLIANO, V., & PELLEGRINI, N.. Effect of cooking on the total antioxidant capacity and phenolic profile of some whole-meal African cereals. **Journal of the Science of Food and Agriculture**, 93(1), 29-36, 2013.

NANI, A., BELARBI, M., KSOURI-MEGDICHE, W., ABDOUL-AZIZE, S., BENAMMAR, C., GHIRINGHELLI, F., . . . KHAN, N. A.. Effects of polyphenols and lipids from *Pennisetum glaucum* grains on T-cell activation: modulation of Ca 2+ and ERK1/ERK2 signaling. **BMC complementary and alternative medicine**, 15(1), 426, 2015.

NANI, A., BRIXI-GORMAT, N., BENDIMRED-HMIMED, S., BENAMMAR, C., & BELARBI, M.. Study of the impact of millet (*Pennisetum glaucum*) on the glucidic and lipidic metabolism in diabetic rats. **Fundamental and Clinical Pharmacology**, 26, 53, 2012.

NANTANGA, K. K., SEETHARAMAN, K., DE KOCK, H. L., & TAYLOR, J. . Thermal treatments to partially pre-cook and improve the shelf-life of whole pearl millet flour. **Journal of the Science of Food and Agriculture**,88(11), 1892-1899, 2008.

NATIONAL CANCER INSTITUTE. **Risk Factors for Cancer**.. 2015. https://www.cancer.gov/about-cancer/causes-prevention/risk / Accessed 15.07.17

NDUTI, N., MCMILLAN, A., SENEY, S., SUMARAH, M., NJERU, P., MWANIKI, M., & REID, G.. Investigating probiotic yoghurt to reduce an aflatoxin B1 biomarker among school children in eastern Kenya: Preliminary study. **International Dairy Jour**nal, 63, 124-129, 2016.

NETTO, D. A. M., & DURÃES, F. O. M.. Milheto: tecnologias de produção e agronegócio (1th ed.). Brasília, DF: **Empresa Brasileira de Pesquisa Agropecuária,** 2005.

NISHIZAWA, N., SATO, D., ITO, Y., NAGASAWA, T., HATAKEYAMA, Y., CHOI, M. R., ... & WEI, Y. M.. Effects of dietary protein of proso millet on liver injury induced by D-galactosamine in rats. **Bioscience, biotechnology, and biochemistry**,66(1), 92-96, 2002.

NKAMA, I., GBENYI, D., & HAMAKER, B. . Effects of Malting and Roasting of Millet and Sorghum on Protein Digestibility, Mineral Availability, Soluble Sugar Composition and Consumer Acceptability of Dakuwa. **Indian Journal of Nutrition**, 2(1), 1-6, 2015.

OBADINA, A., ISHOLA, I. O., ADEKOYA, I. O., SOARES, A. G., DE CARVALHO, C. W. P., & BARBOZA, H. T. (2016). Nutritional and physico-chemical properties of flour from native and roasted whole grain pearl millet (P*ennisetum glaucum* [L.] R. Br**.). Journal of Cereal Science**, 70, 247-252, 2016.

OMOBA, O. S., TAYLOR, J., & KOCK, H. L.. Sensory and nutritive profiles of biscuits from whole grain sorghum and pearl millet plus soya flour with and without sourdough fermentation. **International Journal of Food Science & Technology**, 50(12), 2554-2561, 2015.

OSMAN, M. A. . Effect of traditional fermentation process on the nutrient and antinutrient contents of pearl millet during preparation of Lohoh. **Journal of the Saudi Society of Agricultural Sciences**, 10(1), 1-6, 2011.

OWUSU-KWARTENG, J., TANO-DEBRAH, K., AKABANDA, F., & JESPERSEN, L.. Technological properties and probiotic potential of *Lactobacillus fermentum str*ains isolated from West African fermented millet dough. **BMC microbiology**, 15(1), 261, 2015.

PALANISWAMY, S. K., & GOVINDASWAMY, V.. In-vitro probiotic characteristics assessment of feruloyl esterase and glutamate decarboxylase producing Lactobacillus spp. isolated from traditional fermented millet porridge (kambu koozh). **LWT-Food Science and Technolo**gy, 68, 208-216, 2016.

PATEL, S.. Cereal bran fortified-functional foods for obesity and diabetes management: Triumphs, hurdles and possibilities. **Journal of Functional Foods**, 14, 255-269, 2015.

PEDERSEN, L. L., OWUSU-KWARTENG, J., THORSEN, L., & JESPERSEN, L.. Biodiversity and probiotic potential of yeasts isolated from Fura, a West African spontaneously fermented cereal. **International Journal of Food Microbiology,** 159(2), 144-151, 2012.

PRAJAPATI, M. R., PATEL, V., PAREKH, T., & SUBHASH, R.. Effect of in bio-processing on antioxidant activity of selected cereals. **Asian J Plant Sci** , 3(2), 66-72, 2013.

PRASAD, V. S. S., HYMAVATHI, A., BABU, V. R., & LONGVAH, T.. Nutritional composition in relation to glycemic potential of popular Indian rice varieties. **Food Chemistry**, 238(Supplement C), 29-34, 2018.

PORTAL BRASIL SAÚDE. 2015. http://www.brasil.gov.br/saude/2015/07/diabetes-atinge-9-milhoes-de-brasileiros / Accessed 14.04.17.

QIAN, J.-Y., GU, Y.-P., JIANG, W., & CHEN, W.. Inactivating effect of pulsed electric field on lipase in brown rice. **Innovative Food Science & Emerging Technologies**, 22, 89-94, 2014.

RAGAEE, S., ABDEL-AAL, E.-S. M., & NOAMAN, M.. Antioxidant activity and nutrient composition of selected cereals for food use. **Food Chemistry**, 98(1), 32-38, 2006.

RAI, K., GOWDA, C., REDDY, B., & SEHGAL, S.. Adaptation and potential uses of sorghum and pearl millet **in alternative and health foods. Comprehensive** Reviews in Food Science and Food Safety, 7(4), 320-396, 2008.

RATHI, A., KAWATRA, A., & SEHGAL, S.. Influence of depigmentation of pearl millet (*Pennisetum glaucum* L.) on sensory attributes, nutrient composition, in vitro protein and starch digestibility of pasta. **Food Chemistry**, 85(2), 275-280, 2004.

REICHERT. The pH-sensitive pigments in pearl millet. **Cereal Chemistry**, 56, 291-294, 1979.

RODRIGUES, P. B., ROSTAGNO, H. S., ALBINO, L. F. T., GOMES, P. C., BARBOZA, W. A., & NUNES, R. V. . Aminoácidos digestíveis verdadeiros do milheto, do milho e subprodutos do milho, determinados com galos adultos cecectomizados. **Revista Brasileira de Zootecnia**, 30(6), 2046-2058, 2001.

ROMIER, B., SCHNEIDER, Y.-J., LARONDELLE, Y., & DURING, A. . Dietary polyphenols can modulate the intestinal inflammatory response. **Nutrition reviews,** 67(7), 363-378, 2009.

RONA, R. J., KEIL, T., SUMMERS, C., GISLASON, D., ZUIDMEER, L., SODERGREN, E., . . . MADSEN, C.. The prevalence of food allergy: A meta-analysis. **Journal of Allergy and Clinical Immunology**, 120(3), 638-646, 2007.

SALAR, R. K., PUREWAL, S. S., & SANDHU, K. S.. Fermented pearl millet (*Pennisetum glaucum*) with in vitro DNA damage protection activity, bioactive compounds and antioxidant potential. **Food Research Internation**al, 100, 204-210, 2017.

SALDIVAR, S.. Cereals: dietary importance. **Encyclopedia of Food Sciences and Nutritio**n, Reino Unido: Academic Press, Agosto, London, 1027-1033, 2003.

SALEH, A. S., ZHANG, Q., CHEN, J., & SHEN, Q.. Millet grains: nutritional quality, processing, and potential health benefits. **Comprehensive reviews in food science and food safety**, 12(3), 281-295, 2013.

SANDHU, K. V., SHERWIN, E., SCHELLEKENS, H., STANTON, C., DINAN, T. G., & CRYAN, J. F.. Feeding the microbiota-gut-brain axis: diet, microbiome, and neuropsychiatry. **Translational Research**, 179, 223-244, 2017.

Santos, R., Neves, A. L., Pereira, L. G., Verneque, R., Costa, C. T., Tabosa, J., . . . Gonçalves, L.). Divergence in agronomic traits and performance of pearl millet cultivars in Brazilian semiarid region. Grassland Science, 63(2), 118-127, 2017.

SERNA-SALDIVAR, S., CLEGG, C., & ROONEY, L.. Effects of parboiling and decortication on the nutritional value of sorghum (Sorghum bicolor L. Moench) and pearl millet (*Pennisetum glaucum* L.). **Journal of Cereal S**cience, 19(1), 83-89, 1994.

SCOPUS®(DATABASE), 2018. Search Pearl millet. http://www.scopus.com/. Acessed: 22.02.2018

Shan, S., Li, Z., Guo, S., Li, Z., Shi, T., & Shi, J.. A millet bran-derived peroxidase inhibits cell migration by antagonizing STAT3-mediated epithelial-mesenchymal transition in human colon cancer. **Journal of Functional Foods**, 10, 444-455, 2014.

SHAN, S., SHI, J., LI, Z., GAO, H., SHI, T., LI, Z., & LI, Z.. Targeted anti-colon cancer activities of a millet bran-derived peroxidase were mediated by elevated ROS generation. Food & function, 6(7), 2331-2338., 2015.

SHARMA, S., SAXENA, D. C., & RIAR, C. S.. Analysing the effect of germination on phenolics, dietary fibres, minerals and γ-amino butyric acid contents of barnyard millet (*Echinochloa frumentaceae*)**. Food Bioscience**, 13, 60-68, 2016.

SHARMA, S., SAXENA, D. C., & RIAR, C. S. . Changes in the GABA and polyphenols contents of foxtail millet on germination and their relationship with in vitro antioxidant activity. **Food Chemistry**, 2017.

SHOBANA, S., SREERAMA, Y., & MALLESHI, N.. Composition and enzyme inhibitory properties of finger millet (*Eleusine coracana* L.) seed coat phenolics: Mode of inhibition of α-glucosidase and pancreatic amylase. **Food Chemis**try, 115(4), 1268-1273, 2009.

SHUKLA, K., & SRIVASTAVA, S.. Evaluation of finger millet incorporated noodles for nutritive value and glycemic index. **Journal of Food Science and Techno**logy, 51(3), 527-534, 2014.

SIHAG, M. K., SHARMA, V., GOYAL, A., ARORA, S., & SINGH, A. K.. Effect of domestic processing treatments on iron, β-carotene, phytic acid and polyphenols of pearl millet. **Cogent Food & Agriculture,** 1(1), 1109171, 2015.

SINGH, G., & SEHGAL, S.. Nutritional evaluation of ladoo prepared from popped pearl millet. **Nutrition & Food Science**, 38(4), 310-315, 2008.

SIROHA, A. K., SANDHU, K. S., & KAUR, M. Physicochemical, functional and antioxidant properties of flour from pearl millet varieties grown in India. **Journal of Food Measurement and Characterization,** 10(2), 311-318, 2016.

SRIKANTH, S., & CHEN, Z.. Plant Protease Inhibitors in Therapeutics-Focus on Cancer Therapy. **Frontiers in Pharmacology**, 7, 2016.

TACO. Tabela brasileira de composição de alimentos. **Universidade Estadual de Campinas** (UNICAMP). 2011. 4ª ed. Campinas: NEPA – UNICAMP.<http://www.unicamp.br/nepa/taco/tabela.php?ativo=tabela>.Accessed: 21.02.2018.

TAYLOR, J., BARRION, S., & ROONEY, L.. **Pearl millet—new developments in ancient food grain**. Cereal Foods World (CFW), 55(1), 16. 2010.

TAYLOR, J., & DUODU, K. G.. Effects of processing sorghum and millets on their phenolic phytochemicals and the implications of this to the health enhancing properties of sorghum and millet food and beverage products. **Journal of the Science of Food and Agriculture**, 95(2), 225-237, 2015.

TAYLOR, J. R., & EMMAMBUX, M. N. **Gluten-free foods and beverages from millets** (pp. 119-141). Elsevier, Academic Press: San Diego, CA, 2008.

TAYLOR, J. R. N.. Millet Pearl: **Overview Encyclopedia of Food Grains (Second Edition)** (pp. 190-198). Oxford: Academic Press, 2016.

TBCA. TABELA BRASILEIRA DE COMPOSIÇÃO DE ALIMENTOS. Universidade de São Paulo (USP). **Food Research Center** (FoRC). 2017.Versão 6.0. http://www.fcf.usp.br/tbca/ Accessed: 21.02.2018.

TIWARI, A., JHA, S., PAL, R., SETHI, S., & KRISHAN, L.. Effect of Pre-Milling Treatments on Storage Stability of Pearl Millet Flour**. Journal of Food Processing and Preservation**, 38(3), 1215-1223, 2014.

THIRUMDAS, R., SARAGAPANI, C., AJINKYA, M. T., DESHMUKH, R. R., & ANNAPURE, U. S.. Influence of low pressure cold plasma on cooking and textural properties of brown rice. **Innovative Food Science & Emerging Technologies,** 37(Part A), 53-60, 2016

TOU, E. H., GUYOT, J. P., MOUQUET-RIVIER, C., ROCHETTE, I., COUNIL, E., TRAORÉ, A. S., & TRÈCHE, S.. Study through surveys and fermentation kinetics of the traditional processing of pearl millet (*Pennisetum glaucum*) into ben-saalga, a fermented gruel from Burkina Faso. **International Journal of Food Microbiology**, 106(1), 52-60, 2006.

UGARE, R., CHIMMAD, B., NAIK, R., BHARATI, P., & ITAGI, S.. Glycemic index and significance of barnyard millet (*Echinochloa frumentacae*) in type II diabetics. **Journal of Food Science and Technology**, 51(2), 392-395, 2014.

ULLAH, T. S., SAEED, F., BHATTY, N., ARSHAD, M. U., ANJUM, F. M., AFZAAL, M., . . . AAMIR, M.. Assessment of Therapeutic Potential of Pearl Millet Iron Fortified Cookies through Animal Modeling. **Asian Journal of C**hemistry, 28(11), 2545, 2016.

USDA. United States Department of Agriculture Agricultural. Natural Resources Conservation Service. 2016. **Plants Datebase**. https://plants.usda.gov/java/ Accessed: 21.02.2018.

USDA. United States Department of Agriculture Agricultural Research Service.National Nutrient **Database for Standard Reference** Release 28 slightly revised May, 2016. https://ndb.nal.usda.gov/ndb/ Accessed: 21.02.2018.

VAN RENSBURG, S. J. (1981). Epidemiologic and dietary evidence for a specific nutritional predisposition to esophageal cancer. **Journal of the National Cancer Institu**te, 67(2), 243-251, 1981.

WARE, L. Y., DURAND, N., NIKIEMA, P. A., ALTER, P., FONTANA, A., MONTET, D., & BARRO, N.. Occurrence of mycotoxins in commercial infant formulas locally produced in Ouagadougou (Burkina Faso). **Food Control**, 73, 518-523, 2017.

WHO. World Health Organization. **Media centre-Diabetes**. 2017a. http://www.who.int/mediacentre/factsheets/fs312/en/ Accessed 20.11.17

WHO. World Health Organization. **Media centre-Cancer**. 2017b. http://www.who.int/mediacentre/factsheets/fs297/en/ Accessed 14.04.17

WHO & UNPARTNERS . Country Statistics and Global **Health Estimates. World Health Organization.** http://www.who.int/gho/countries/bra.pdf/ ; 2015. http://www.who.int/gho/countries/ind/en/ Accessed 14.07.17

WILSON, J., JURJEVIC, Z., HANNA, W., WILSON, D., POTTER, T., & COY, A. Host-specific variation in infection by toxigenic fungi and contamination by mycotoxins in pearl millet and corn. **Mycopathologia**, 161(2), 101-107, 2006.

ZHANG, L., LIU, R., & NIU, W. Phytochemical and antiproliferative activity of proso millet. **PloS one**, 9(8), e104058. 2014.

CAPÍTULO II

IMPACTS OF OHMIC HEATING ON DECORTICATED AND WHOLE PEARL MILLET GRAINS COMPARED TO OPEN-PAN COOKING

IMPACTS OF OHMIC HEATING ON DECORTICATED AND WHOLE PEARL MILLET GRAINS COMPARED TO OPEN-PAN COOKING

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Impacts of ohmic heating on decorticated and whole pearl millet grains compared to open-pan cooking

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ABSTRACT

The effects of two cooking methods, ohmic heating (OH) and conventional open-pan (CONV) on the cooking yield, texture profile analysis (TPA), color parameters, water absorption (WAI), solubility index (WSI) and pasting properties (RVA) of pearl millet grains (*Pennisetum glaucum* (L.) R. Br.) were investigated. Whole grains were pre-processed by mechanical decortication for 5 min to obtain a 9.1% degree of decortication. The optimum cooking times (OCT) of the whole and decorticated grains were 30 min and 20 min, respectively. The grains were cooked by the OH and CONV methods using a millet-water ratio of 1:2. The OH cooking yield was lower than CONV. The OH cooking did not soften the grains faster than CONV cooking. OH affected the TPA and color of decorticated grains significantly, resulting in greater L* than the CONV-Decorticated. OH did not affect WAI and WSI in comparison to CONV method. The paste viscosity profiles of whole and decorticated grains cooked by both heating methods were similar indicating a comparable effect of starch conversion. This research shows that the main factor affecting the cooking process was the pericarp of the grain rather than the heating method.

Keywords: *g*luten-free cereals; color; texture; viscosity

1 INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is a gluten-free cereal crop with potential use in food safety and human nutrition; however, it is still relatively unknown by consumers and the food industry (TAYLOR, 2016). This cereal crop has many advantages, including its low production costs, greater resistance to drought and heat than wheat, and higher protein and dietary fiber content than traditional cereals such as rice and maize (DIAS-MARTINS *et al.,* 2018). The whole and decorticated cooked grains are commonly consumed in meals similar to rice such as *couscous*, a staple food of North Africa, also known as semolina. In addition, it can be milled and its flour, raw or precooked, can be used to produce a wide range of foods such as flatbreads, porridges, pastas and beverages (AKINOLA *et al.,* 2017).

Decortication and cooking are the most common methods used to process pearl millet because they are simple and inexpensive methods, however a variation of methods may produce different end results (DIAS-MARTINS *et al.,* 2018).The decortication process, also known as dehulling, is the removal of the bran (pericarp and germ) of the millet grains, in order to promote improvements in the quality attributes, such as palatability, grain coloration, reduction of phytic acid and fat content (HAMA *et al.,* 2011). However, decortication may cause nutrient losses and modifications of the physical properties. Such alterations depend on the moisture, the type of processing (mechanical or manual) and degree of decortication (DHARMARAJ *et al.,* 2014; HAMA *et al.,* 2011).

There are various factors that can influence the characteristics of the cooked grains, such as: variety, type of pre-processing applied (eg. decortication), grain size, water/grain ratio, cooking time, temperature profiles and cooking method (YU *et al.,* 2009). Different methods of cooking have been applied to pearl millet grains such as, boiling in an open-pan (CONV), use of a pressure cooker and in a microwave oven (HITHAMANI & SRINIVASAN, 2014). Another less well known method for cooking is ohmic heating (OH), which has been reported as a promising technology for cooking cereals, such as rice and maize, due its high energy efficiency, short cooking time, reduced energy consumption and environmental friendly technology (GAVAHIAN *et al.,* 2019, GAYTÁN-MARTÍNEZ *et al.,* 2011; JITTANIT *et al.,* 2017). However, it has not been described for cooking pearl millet grains unti now.

The basic principle of OH is the passage of an electric current (usually AC) through raw food promoting instantaneous and homogeneous heating by the conversion of electrical energy into thermal energy, also known as the Joulle effect (GAVAHIAN *et al.,* 2018 a,b). Due to the Joulle effect, the OH method presents greater energy efficiency than conventional methods, such as open pan boiling (CONV), which uses an indirect heat transfer mechanism (convection/conduction). The uniform and rapid heating rates depend directly on the electric field and the electrical conductivity of the food (CAPPATO *et al.,* 2017). In addition, this technology has been proposed as a potential alternative to replace traditional processes such as bleaching and pasteurization as well as extraction of essential oils, because in this latter case it increases the extraction yield, besides it reduces overall operational costs (GAVAHIAN *et al.,* 2012).

Besides thermal effects, OH also may promote non-thermal effects depending on the raw material and the process conditions such as temperature, frequency and electric field strength that can cause minor cellular damage to plant tissues (GAVAHIAN *et al.,* 2018 a,b). Moreover, according to Kaur & Singh. (2016), OH may affect some functional characteristics of the products such as texture, color, water absorption index (WAI), water solubility index (WSI) and pasting properties.

Thus, the aim of this study was: (1) to determine the effects of mechanical decortication on the physical properties of cooked pearl millet grains, (2) to determine the optimum cooking time of decorticated and whole grains, (3) to compare the quality attributes such as texture profile analysis (TPA), color parameters, pasting properties (RVA), water absorption (WAI) and solubility (WSI) index of pearl millet cooked by OH and CONV.

2 MATERIALS AND METHODS

2.1 Pearl millet grain

Pear millet grains (*Pennisetum glaucum* (L.) R. Br) cultivar BRS 1502 harvested in 2016 were produced and donated by Embrapa Milho e Sorgo (Sete Lagoas, Brazil). The grains were manually cleaned and stored in a freezer at -18ºC until processing.

2.2 Sample preparations

The grains were dried in a fan oven at 30 °C for 3 h until reaching a water content of 10.5% (w/w %).The size of the grains was measured by weighing 100 g on previously weighed stainless steel sieves with the following meshes2.38 mm, 2.00 mm, 1.68 mm and 1.40 mm fitted on a ROTAP RX-29-10 shaker (W.S. Tyler, St. Albans, USA) for 20 min. The weight of the samples retained by each sieve was recorded and expressed as % retention.

Decortication was carried out with whole pearl millet grains in a mechanical abrasion rice dehusking machine (model MT-97, nº3788-5, Suzuki, Brazil) for 5 min. Extraction rate (%) is the proportion of the weight of decorticated grains of the initial weight of the grains, according to Yetneberk et al . (2005). The degree of decortication was calculated as 100 minus the extraction rate. After decortication, the decorticated grains were also classified by size.

2.3 Optimum cooking time (OCT)

The OCT of whole and decorticated pearl millet grains was defined according to AACC (2000), with adaptations. About 10 g of whole and decorticated grains were added separately to a glass beaker containing 140 mL of boiling water (~ 98ºC). The cooking time calculation started immediately after immersion. After every 4 min (whole grains) and 2 min (decorticated grains) of cooking time, a few grains were collected and pressed between two clean glass plates. OCT was recorded when at least 95% of the grains were no longer opaque or did not have a translucent center. The crushed samples were then photographed with an EOS 1000D digital camera (Nikon, Tokyo, Japan).

2.4 OH and CONV cooking

After defining the OCT, the grains were cooked by OH and open pan boiling (CONV). For both processes (OH and CONV), the grains were added after the water reached 98 °C with a 1:2 grain/water ratio and 0.1% of NaCl. The cooking processes were carried out under the same temperature profiles (98 °C ± 2 °C) in order to investigate the effects of the electric field on quality attributes.

The treatments were defined as: whole and decorticated grains cooked with conventional treatment (CONV-Whole and CONV-Decorticated) and OH treatment (OH-Whole and OH-Decorticated). The OH system consisted of a voltage source (Variac - 10140, São Paulo, Brazil), stainless steel electrodes, T-type (Copper/Constantan) thermocouples, digital multimeters (Icel - MD 6365, Manuas, Brazil) and a polymer tank (cooking chamber). The electrodes (15 x 9 cm -length and height) were fixed to a Teflon® support, and the distance between them was 9.2 cm. The OH system applied an AC voltage at a fixed frequency (60 Hz). A data acquisition system (digital multimeters) was used to collect the signals of the alternating current, voltage and temperature at 20 s intervals. The electric field (V/cm) was calculated from the voltage data (V) in relation to the distance between the electrodes (9.2 cm). A glass rod was used to stir the ingredients in the polymer tank to ensure an even distribution of heat in the ohmic cell. More details and a complete description of the OH apparatus can be found elsewhere (Costa et al., 2018).

All experiments were carried out in duplicate. After OH and Conventional cooking, the grains were drained for 3 min and divided into two portions, according to the type of analyses. First portion was left to cool at room temperature prior to analysis described in item **2.6.1** and the second portion was stored in a refrigerator (5 °C) for 24 h prior to the analysis described in **2.6.2.**

2.5 Electrical conductivity measurement and energy consumption

The electrical conductivity (σ) and the total energy consumption (E) were determined for the OH cooking according to the following equations, **Eq. 1** and **Eq. 2** (Gavahian et al., 2018 c). Due to the small size of the millet grain, the electrical conductivity was measured using the water/grain solution as an indirect method to determine the electrical conductivity of the millet grains.

$$\sigma = IL/AV \qquad \textbf{Eq. (1)}$$

Where σ = Electrical conductivity (S/m); I is the electric current (A); L is the distance between two electrodes (m); V is the applied voltage (V); A is surface area of the electrodes (m^2).

$$E = \sum(VIt) \qquad \textbf{Eq. (2)}$$

E= Electrical energy consumption (J); I is the electrical current (A); V is the applied voltage (V); t is the time interval (s).

2.6 Quality attributes of pearl millet grains

2.6.1 Cooking yield

The Cooking yield was calculated according to **Eq. 3** and measured immediately after cooking the grains.

$$\%\ \text{Cooking Yield} = \left(\frac{\text{weight of cooked grains}}{\text{weight of raw grains}}\right) \times 100 \qquad \textbf{Eq. (3)}$$

2.6.2 Texture Profile Analysis (TPA) and Color Parameters of cooked pearl millet grains

In order to determine the Texture Profile Analysis and Color Parameters, the cooked pearl millet grains were removed from the refrigerator and kept at room temperature (25 ± 2 °C) in an airtight container. The TPA included the determination of the hardness, adhesiveness, cohesiveness, springiness, gumminess and chewiness of the cooked grains. Texture analysis was conducted on a Texture Analyzer TA XT Plus (Stable Micro Systems, Surrey, UK) interfaced with the computer software Texture Exponent version 6.1.11 (Stable Micro Systems, Surrey,UK) and fitted with a 30 kg load cell. A two-cycle compression force versus time program was used for each test, which consisted of compressing the samples till 90% of the original cooked grain thickness, returned to the original position and then compressed again. A cylindrical probe of 31 mm was used to compress 3 grains. The probe penetration distance in the samples was 3 mm and the test velocity was 1 $mm.s^{-1}$. Twenty measurements were performed on each sample for both treatments and the results are presented as mean values.

Color parameters were measured using a Color Quest XE (Hunter Assoc. Laboratory, VA, USA) colorimeter equipped with a D65/10 illuminant with an aperture size of 1mm. The color parameters $a*$ (redness-greenness), $b*$ (yellowness-blueness), and $L*$(brightness) of the CIELAB scale were determined and were used to calculate, chroma ($C*$), hue angle ($h°$) and color variation ($\Delta E*$) according to **Eq.4**, **5** and **6** (CIE, 2004). Four replicates were performed for each sample.

$$C^* = \sqrt{(a^*)^2 + (b^*)^2} \qquad \textbf{Eq. (4)}$$

$$h° = arctan(b^*/a^*) \qquad \textbf{Eq. (5)}$$

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad \textbf{Eq. (6)}$$

Where: $\Delta a^* = a_{conv}^* - a_{OH}^*$; $\Delta L^* = L_{conv}^* - L_{OH}^*$; $\Delta b^* = b_{conv}^* - b_{OH}^*$.

2.7 Functional properties of cooked pearl millet flours

Cooked grains (whole and decorticated) of both treatments were dried in a fan oven at 30 °C for 24 h, until reaching a final moisture of 8%. Then, they were milled in two stages to gradually reduce particle size: for the first stage a 3600 disc mill (Perten Instruments, Huddinge, Sweden) was used and in the second stage a hammer mill LM3100 (Perten Instruments, Huddinge, Sweden) was used and this latter one was fitted with a 0.8 mm mesh. The resulting flour was vacuumed packed in polyethylene until further analysis. However, the starch content present in the decorticated and non-decorticated grains was not standardized.

2.7.1 Water absorption index (WAI) and Water solubility index (WSI)

Water absorption index (WAI) and water solubility index (WAI) were determined by the methodology described by Anderson et al. (1970) with modifications. WAI and WSI of the cooked flours were determined in quadruplicate. Approximately 1 g of sample was weighed in falcon tubes containing 10 mL of distilled water and homogenized for 20 s in a vortex mixer. Then, in order to promote complete hydration, the tubes were kept at 25 ± 5 °C without agitation for 30 min. After which, the tubes were centrifuged in a Universal 320R (Hettich, Tuttlingen, Germany) for 15 min at 7000 rpm. The supernatant was dried in a fan oven at 105ºC until constant weight. The wet precipitated was weighed. The WSI and WAI were calculated according to **Eq.7**and **8**, respectively.

$$\text{WAI}\left(\frac{\text{g precipitate}}{\text{g dry weight}}\right)=\frac{\text{Weight gain by precipitate}}{\text{Dry weight of sample}} \qquad \textbf{Eq. (7)}$$

$$\text{WSI}(\%)=\frac{\text{Weight of dispersed solids in the supernatant}}{\text{Weight of the flour}}\ \text{X}\ 100 \qquad \textbf{Eq. (8)}$$

2.7.2 Pasting properties

The pasting properties of the pearl millet cooked flour samples were analyzed using a Rapid Visco Analyzer (RVA) series 4 model (Newport Scientific PTY Ltd, Warriewood, Australia). Approximately, 3 g of cooked flours with particle sizes between 212 and 106 µm and moisture adjusted to 14 g of water/100 g were added to 25 g of distilled water. The temperature profile included initially mixing and holding the specimen with the paddles rotating at 160 rpm at 25 ºC for 2 min, heating to 95 °C (held for 3 min) and then cooled to 25 °C, resulting in a total time of 20 min. The heating and cooling phases were performed with temperature gradients of 6 ºC/min. The values of the initial paste viscosity, maximum viscosity, final viscosity and setback (tendency of retrogradation) were expressed in cP.

2.8 Statistical analysis

Statistical analyses were performed using Excel and Statistic software v.7.0 (Statsoft Inc., Tulsa, USA). The Fisher's means comparison test with a confidence level of 95% was used to compare the results.

3 RESULTS AND DISCUSSION

3.1 Sizes of pearl millet grains

The mean diameter of 54.9% of the whole pearl millet grains was 2.0 mm, 28.2% were less than 2 mm (1.40mm up to 1.68 mm) and 16.9% had a diameter greater than 2.38 mm (**Table 1**). This result for the mean diameter of the whole grains was similar to that found (2.0- 2.5 mm) by Lestienne *et al*. (2007) and Hama *et al.* (2011). The variation in size of pearl millet grains has been attributed to grains belonging to the same panicle with different degrees of physiological maturity. In addition, its size is correlated to its location on the panicle. In general, grains located at the apex of the panicle are smaller than those located in the center or at the base. This non-uniformity of size can reduce the commercial profitability of this cereal, as well as, hamper standardization because the size of the grains directly influences the physical properties, such as cooking time. Larger grains have a larger endosperm which in turn requires longer cooking time to promote complete starch gelatinization, unlike small grains.

Table 1
Size of grains (*Pennisetum glacum* (L.) R. Br., cultivar BRS1502) and decortication characteristics

	Whole millet grains	Decorticated millet grains
		
Size of grains^{C}		
Diameter of grains (mm)		
2.38 mm	16.9 ± 2.89^{a}	7.1 ± 3.14^{b}
2.00 mm	54.9 ± 2.43^{a}	55.3 ± 0.87^{a}
1.68 mm	26.0 ± 1.58^{a}	33.4 ± 3.48^{b}
1.40 mm	2.2 ± 2.35^{a}	3.1 ± 0.07^{a}

Decortication characteristics[D]		
Extraction rate (%)	-	90.9 ± 2.23
Degree of decortication (%)	-	9.1 ± 2.23
Bran removed (%)	-	6.3 ± 0.40
Broken/Loss (%)	-	2.8 ± 2.63

[C] Data are expressed as mean ± standard deviation of 4 observations. Different superscript letters in the same row correspond to significant differences ($p < 0.05$);

[D] Results are mean standard deviation of, n= 4 observations. Moisture of the pearl millet grains- 10.5%.

3.2 Effects of the decortication process

Table 1 shows decortication characteristics of pearl millet grains. Decortication reduced the number of 2.38 mm diameter grains by 46% and increased the number of 1.68 mm diameter grains by 28%. The extraction rate was 90.9% and around 2.8% of the grains were broken due to the mechanical decortication method used. The reduction in grain size and extraction rate (%) can impact directly on the physical properties, such as cooking time, texture, color, water absorption capacity and viscosity according to Mohapatra & Bal (2006). In addition, these authors suggested that it is necessary to choose the appropriate extraction rate for each cultivar to minimize nutritional losses and improve cooking/eating qualities.

Different extraction rates have been reported in the literature for pearl millet grains (HAMA *et al.,* 2011; LESTIENNE *et al.,* 2007).These differences are due to the different conditions involved in the process, such as moisture content, method of decortication (manual by friction or mechanical by abrasion) and type of machine used. Abdalla & Mustafa (2014) reported similar results of extraction rate (89.5%) in grains of *Pennisetum glaucum*, variety ICTP 8203 with 4% moisture content decorticated using an abrasive polisher. In addition, the same authors reported similar values to the current study: 2.5% of broken grains and 7% of bran removal. Hama et al. (2011) reported an extraction rate of 88.8% in pearl millet grains (*Pennisetum glaucum*, variety Gampela) with 10% moisture using mechanical abrasion. According to Lestienne et al. (2007), an 88% extraction rate in grains with 15% moisture led to efficient separation of the outer layers from the starchy endosperm and to a slight abrasion of the lower layers but without any damage to the starchy endosperm or change to the protein and zinc content. In contrast, this rate was not enough to reduce the lipid and phytate content.

According to the identity and quality standards described by the Codex Alimentarius Commission (2007), it is recommended that pearl millet grains should have a decortication degree of 20% maximum (extraction rate of 80% maximum). Preliminary tests in this present study showed that a decortication degree higher than 9%, despite having promoted a greater removal of the germ and pericarp, resulted in a significant increase of broken grains. This high percentage of broken grains is because the germ is strongly incorporated in the endosperm and due to the small size of the grain, making abrasive decortication difficult.

3.3 Optimum cooking time (OCT)

The optimal cooking time for pearl millet is reached after the starch granules have taken up sufficient water. After this time, 95% of the grains present a soft texture and a translucent center when pressed between two glass slides, evidencing starch gelatinization, and thus confirming that the grains are suitable for consumption (**Fig. 1)**.

The optimal cooking time (OCT) for whole and decorticated pearl millet grains was 30 min and 20 min, respectively. The results showed that decorticated pearl millet cooked faster than whole grains. This was due to the fact that decorticated grains no longer had the natural pericarp barrier to water penetration, and also they were slightly smaller in size than whole grains. As stated the results showed a significant lower cooking time for decorticated millet (20 min) compared to whole grain (30 min), which reveals the advantages associated with decorticated millet in terms of saving time and energy.

However, only one study (SIROHA & SANDHU, 2017) was found in the literature (research based on the Scopus®, 2018 abstract and citation database) defining the OCT by analytical methods used in that work. In general, the studies found only reported the cooking effect at a pre-defined time and temperature, without informing how this time and temperature were determined (N'DRI *et al.,* 2013; PUSHPARAJ &UROOJ, 2014; CHANDRASEKARA *et al*., 2012).

N'Dri *et al.* (2013) cooked whole pearl millet grains (*Pennisetum glaucum*, variety PVNE, Cote d'Ivoire) at 100 °C for 15 min, which was thesame cooking time used by Hithamani & Srinivasan (2014) for *Pennisetum glaucum,* India. In contrast, Eyzaguirre *et al*. (2006) cooked whole grains (*Pennisetum glaucum,* variety IKMP-5, Burkina Faso) at 100 °C for 5 min, while Pushparaj & Urooj (2014) cooked whole grains for 30 min in an open pan with boiling water (1:1). Chandrasekara *et al.* (2012) cooked the decorticated grains *Pennisetum glaucum* (L.) R. Br., India for 30 min in boiling water. These different studies show that the binomial time x temperature for cooking pearl millet present a great variation.

Therefore, it is essential to determine the OCT by analytical methods in order to standardize the cooking parameters.

Other small millets, such as finger millet showed lower optimum cooking times than pearl millet. Shobana & Malleshi (2007) reported an OCT of whole grain and decorticated (15% degree of decortication) of finger millet (*Eleusine coracana* Indaf 5), respectively, 17 min and 5 min. Dharmaraj *et al.* (2014) reported the same cooking time (6min) for decorticated grains of finger millet (*Eleusine coracana* GPU 28). For barnyard millet (*Echinochloa frumentacea* Link), Veena Bharati et al. (2010) reported an OCT ranging from 8-12 min for decorticated grains.

Although pearl millet grains have different characteristics from rice, the OCT of pearl millet is similar to rice grains, showing that they could be consumed as rice grains. Comparing the results with whole and polished rice grains, OCT ranged between 28-37 min and 13-24 min, respectively (CHEN *et al.,* 2017; MOHAPATRA & BAL, 2006; MONTEIRO *et al.,* 2016). These variations are due to many factors, such us, the variety of the rice, storage time and conditions, moisture content, water-to-rice ratio, the amylose content and polishing degree. These factors may influence the OCT of pearl millet grains, so further research is needed along these lines, because a lack of standardization of optimal cooking time can cause various effects on the physical, chemical and sensorial properties of the cooked grains.

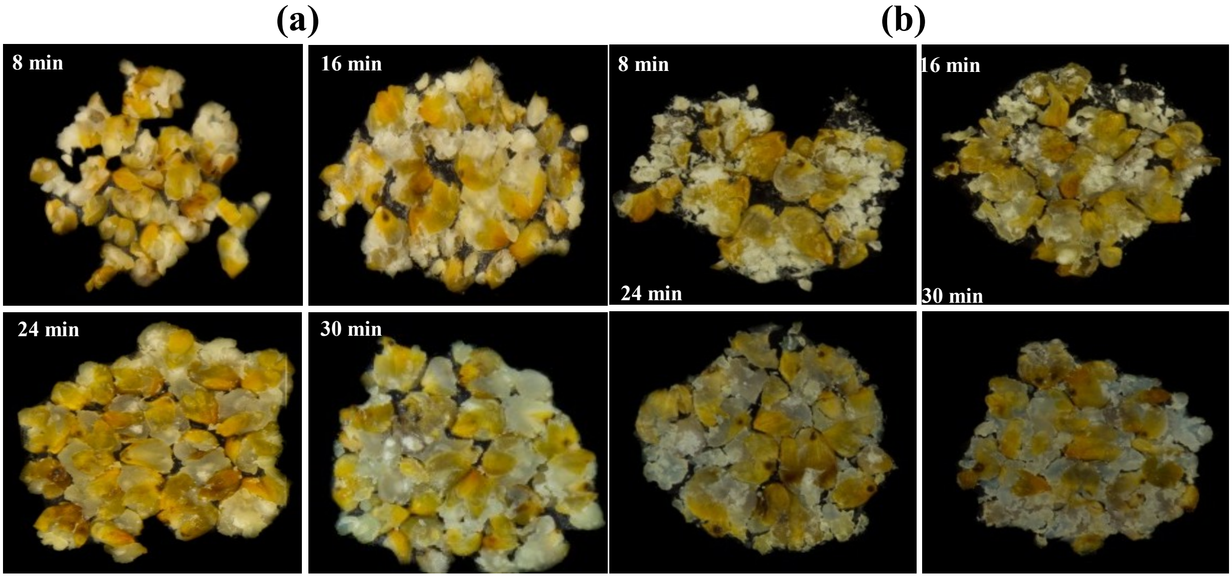
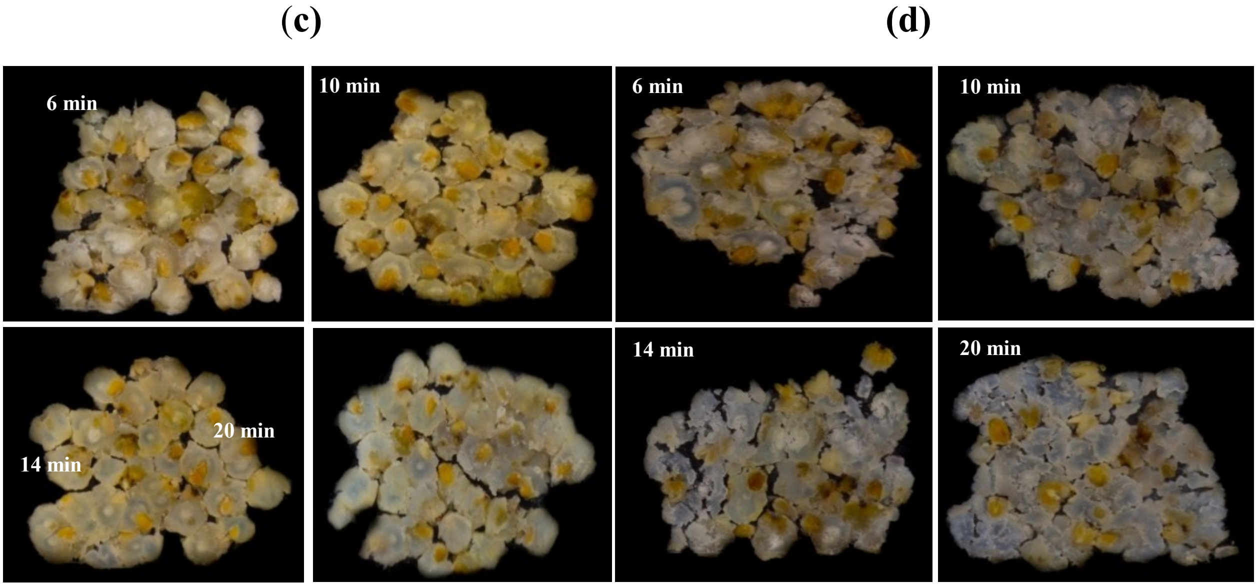


Fig. 1. Pearl millet grains cooked at different cooking times (98ºC) and compressed under glass plate (a) CONV-Whole; (b) OH-Whole



Cont.Fig. 1. Pearl millet grains cooked at different cooking times (98ºC) and compressed under glass plate (c) CONV-Decorticated; (d) OH-Decorticated

3.4 OH cooking parameters

The electrical conductivity (EC), energy consumption and electric field applied by OH cooking are important parameters and data for the system, since they can describe the process and help to understand the effects of OH on the physical properties of foods (GAVAHIAN *et al.*, 2019).However, these parameters are dependent on the size and shape of the food material, pre-processing applied, process temperatures and the mineral salts in solutions (GAVAHIAN *et al.,* 2019).

The results of the electrical conductivity (S/m) and electric field (V/cm) obtained during the OH cooking of the millet grains at 98 °C with 0.1 M salt solution are illustrated in **Fig. 2**. The results demonstrate that pearl millet grains, due to their small size, presented low electrical conductivity. The electrical conductivity of the decorticated grains (0.45–0.55 S/m) was slightly higher than that of whole grains (0.45–0.50 S/m). This was probably due to the removal of the pericarp, which increased the exposure of the nutrients and, consequently, leaching of intracellular materials. These results were similar to those reported by Jittanit et al.(2017), who found 0.2-0.9 S/m for rice samples cooked by OH at ~100ºCat 0.1 M salt solution.

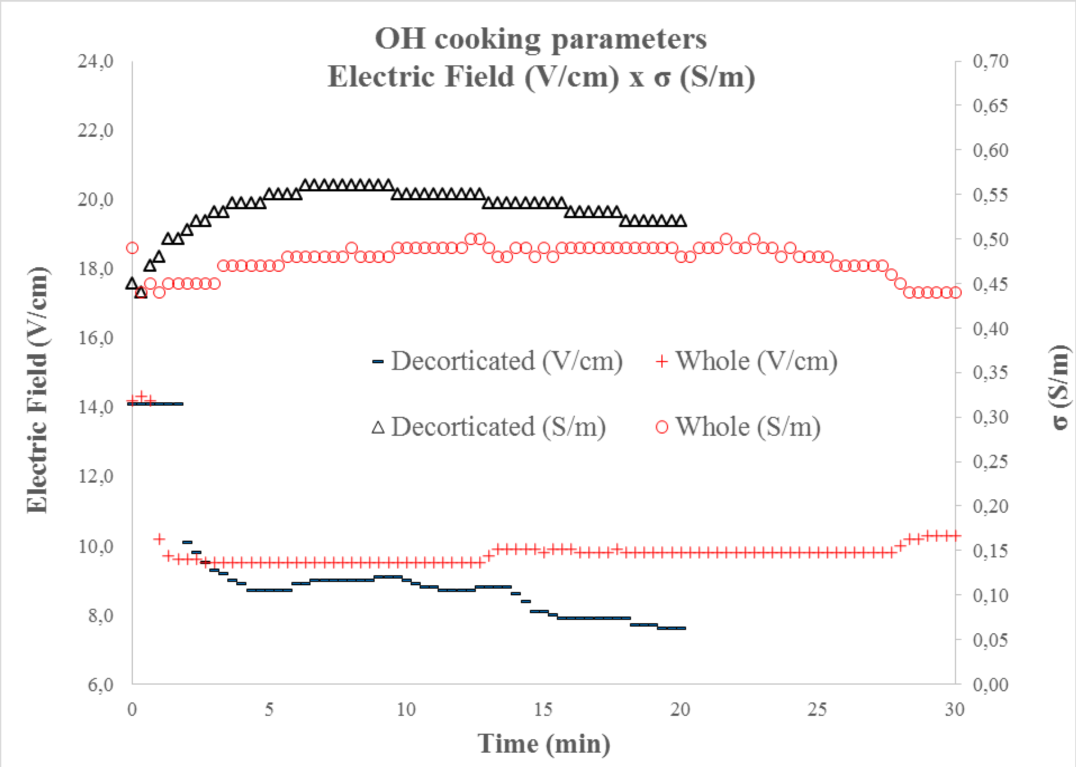


Fig. 2. OH cooking parameters: Electric Field (V/cm) x σ (S/m).

The OCT for both grain types and both methods (Section 3.3) showed that 30 and 20 min respectively was required, for whole and decorticated grains (**Fig.1**). These findings indicate that the ohmic heating parameters used in this work, did not promote a reduction of cooking time when compared to the conventional cooking method. This observation can also be seen in the texture profile analysis displayed in **Table 2**. These results contrasted to the studies of Gavahian *et al.* (2019) and Jittanit *et al.* (2017) that reported that rice grains cooked by OH showed shorter cooking times when compared to the conventional cooking method. This may be attributed to the differences in the raw materials, equipment, cooking parameters and salt concentration.

The total energy consumption for decorticated and whole grains was 438.88 kJ and 504.63 kJ, respectively. Considerably lower cooking time (20 min) for the decorticated grains, compared to whole grains (30 min), reveals the advantages associated with decorticated millet, in terms of saving time and energy. This information indicates that further evaluations of the electrical parameters are necessary.

3.5 Quality attributes of pearl millet grains

3.5.1 Cooking yields of pearl millet grains by OH and CONV cooking

Cooking yields are important factors of quality because they serve as guidelines for consumers and the food industry. The cooking yield results of the pearl millet grains are presented in **Table 2**. The cooking method significantly affected the yield of the whole pearl grains. In general, cooked grains by OH had a lower yield.

The CONV-Whole grain cooking yield (279%) was significantly higher than the OH-Whole grain cooking yield (195%). This result is probably because the pericarp acts as a physical barrier to the electrical conductivity (S / m), which in turn, causes a reduction to the passage of electrons, thus decreasing the effect of OH on the starch-rich endosperm. In other words, the pericarp may have reduced the electrons passing through the food, as observed in **Fig 2**. On the other hand, OH-Decorticated and CONV-Decorticated grains did not differ significantly, which was attributed to the absence of the pericarp that allowed a greater number of free electrons to pass through the food, hence increased the electrical conductivity, which in turn, improved the hydration process.

The cooking yield results for cooked decorticated pearl millet, for both treatments (cooking yield~ 244%), had slightly smaller values than boiled polished rice reported in the literature. Monteiro *et al.* (2016) and Paraginski *et al.* (2014) reported that the polished cooked rice grains cooking yield varied from 249 to 272%, and had values ~ 298% for whole cooked rice. However, comparing our results, with those reported by Veena Bharati *et al*. (2010) for nine varieties of cooked decorticated barnyard millet (average 103%), cooked decorticated pearl millet grains presented higher cooking yields.

Table 2: Cooking yields and textural attributes of whole and dehulled grains cooked by conventional and OH methods

Treatments	Cooking Yield (%)	Hardness (N)	Adhesiveness (N.s)	Springiness	Cohesiveness	Gumminess (N)
CONV-Whole	279±0.23[a]	34.57±7.18[a]	0.01±0.004[b]	0.37±0.07[a]	0.24±0.03[a]	9.77±2.32[a]
OH-Whole	195±0.32[b]	37.67±9.48[a]	0.01±0.004[b]	0.37±0.06[a]	0.24±0.03[a]	9.64±2.09[a]

CONV-Dehulled	259±0.02[a]	11.97±1.18[c]	0.03±0.006[a]	0.30±0.05[b]	0.18±0.01[b]	2.17±0.64[c]
OH-Dehulled	230±0.28[a]	21.21±2.97[b]	0.03±0.011[a]	0.26±0.04[b]	0.20±0.03[b]	4.86±1.35[b]

*Values cooking yield are mean ± standard deviation (n=4). Values of texture are mean standard deviation, n= 20 observations. Different letters in the same column indicate significant differences between samples ($p < 0.05$).

3.5.2 *Texture Profile Analysis (TPA) of cooked pearl millet grains* by OH and CONV cooking

The textural attributes of cooked grains by OH and CONV treatments are presented in **Table 2.** For both cooking processes, the whole cooked grains had higher value of hardness, springiness, cohesiveness, gumminess than the decorticated grains ($p < 0.05$). In contrast, whole cooked grains showed lower adhesiveness than decorticated grains ($p < 0.05$). No significant difference was observed in all textural attributes for OH-Whole *vs* CONV-Whole ($p > 0.05$). Probably, the moderate electric field applied (OH cooking) did not promote a significant effect on the texture parameters due to the low conductivity of the grains. On the other hand, the electric field on decorticated grains significant affected the texture attributes (hardness and gumminess values) of the grains.

Hardness is the maximum force required to compress the sample and the most important parameter for the evaluation of the quality of a cooked cereal (YU *et al.,* 2009).In this present study, OH-Whole did not have lower hardness than CONV-Whole when submitted to the same OTC. However, various other studies have revealed that cooking foods by OH promoted significantly lower hardness than other cooking methods (FARAHNAKY *et al.*, 2012; FARAHNAKY *et al.,* 2018; JITTANIT *et al.*, 2017). Farahnaky et al. (2012) reported that root vegetables cooked by ohmic heating presented lower hardness than those cooked by either conventional or microwave methods. In another study, Farahnaky et al. (2018) reported that vegetables (kohlrabi, turnip, potato and radish) cooked by OH (high-intensity) presented a 90% reduction of initial hardness in a shorter time (7 min total) than microwave (20min) and conventional (60min) cooking. These results show that the reduction of cooking time by OH depends on the food and parameters of processes used such as the electric field, voltage and power (FARAHNAKY *et al.,* 2012).

Higher hardness of whole grains is due to the make-up of the pericarp of the whole pearl millet grains, which have fibers, proteins and lipids that together have greater rigidity. The removal of the pericarp by decortication promotes better absorption of water and consequently, lower hardness. The hardness of OH-Decorticated (21.2N) grains was significantly higher than the CONV-Decorticated (11.9 N) grains ($p<0.05$), showing the influence of the electric field during OH cooking, which provides a more uniform heating and does not cause as many ruptures in the grains as in CONV cooking, thus making it more difficult to reduce the hardness and increase the water absorption.

Adhesiveness is defined as the negative force area for the first bite and measured with a cylindrical probe, which is pressed, onto the surface of the food after which the force to pull the probe off is measured (BOURNE, 2002). Although the values found for both treatments was very small, there was a significant difference between the whole and decorticated grains ($p<0.05$). This is due to the absence of the pericarp in the decorticated grains, which promotes greater exposure to the endosperm facilitating the adhesion of the grains to the probe. According to Mohapatra & Bal. (2006) adhesiveness of cooked rice increases with a greater degree of milling. The results showed that OH cooking did not promote significant changes in the adhesiveness of the grains.

Springiness is an attribute related to the height that the grain recovers during the time between the end of the first bite and the beginning of the second bite (Bourne, 2002). A higher springiness value of whole grains (CONV or OH cooking) shows that decortication promoted significant changes in grain structure, however no significant difference between the two cooking process was observed ($p>0.05$). Dharmaraj et al. (2014) reported a springiness value of 0.30 for decorticated finger millet grains, which is the same value obtained in this work for CONV-decorticated.

Cohesiveness may be measured as the rate that food disintegrates under mechanical action and it can be a good indicator of how the sample holds together upon cooking (YU *et al*., 2009). Greater mechanical resistance is required to disintegrate whole grains than decorticated grains, because the presence of the pericarp, the outer layer of the grains, provides hardness and cohesiveness. Similar results were obtained for decorticated finger millet. Dharmaraj et al. (2014) reported cohesiveness of 0.20 in cooked decorticated finger millet.

Gumminess is defined as the product of the hardness x cohesiveness of the grains (BOURNE, 2002). OH-Decorticated had greater gumminess than CONV-Decorticated (4.86 and 2.17, respectively), due to the higher hardness value of OH-Decorticated (21.21 N).

Dharmaraj et al. (2014) reported cohesiveness values of 0.09 in cooked decorticate finger millet, which is less than the decorticated pearl millet grains.

3.5.3 Color parameters of cooked pearl millet grains by OH and CONV cooking

The color parameters (a^*, b^*, L^*, $h°$, C^*) of cooked pearl millet grains are given in **Table 3**. The whole grains gave smaller values of L^* and higher values of a^* than the decorticated grains. This is due to the removal of pigments, such as flavonoids, during the decortication process (DIAS-MARTINS *et al.* 2018). The difference in color can be seen in the photographs (**Table 1**). OH did not cause any significant changes in the color of whole grains (L^*, b^* and C^* values - $p > 0.05$). There was a difference ($p < 0.05$) only for the a^* value between treatments; however, this difference was very small (Δa^*=0.32) and may not even be perceptible to the human eye. The study conducted by Gavahian et al. (2019) also revealed that lightness (L*) and color intensity (C*) of rice grains cooked by OH for 7.5 min did not differ significantly from the grains cooked by microwave and conventional method for the same cooking time. The authors obtained values of L* of 78.6 and C* of 5, which were higher than that found in millet grains.

Significant differences were observed between CONV-Decorticated and OH-Decorticated for all color values ($p<0.05$). CONV-Decorticated showed smaller lightness values (ΔL^*=-2.82) than the OH-Decorticated($p< 0.05$). The b^* and a^* values of the OH-Decorticated led to a decrease in yellowness and decrease in redness compared to CONV-Decorticated. This confirms that the reduction of color intensity is characterized by the chroma (C^*= 10.36). The hº angle shows the location of the color in a three-dimensional diagram; thus indicating that the decorticated grains have a value closer to pure yellow (90°) than whole grains.

The Color difference (ΔE^*) between CONV and OH of whole grains was ΔE^*=0.49 and of decorticated grains was ΔE^*=3.07.According to Francis &Clydesdale (1975), a color difference $\Delta E^* < 1$ is not perceptible to the human eye, while a color difference $\Delta E^*> 3$ is perceptible to the human eye. Thus, OH cooking causes significant changes in the coloration of decorticated pearl millet grains (ΔE^*=3.05), which can be seen in **Table 3**.

Table 3 :Color parameters of cooked pearl millet grains by conventional and OH cooking.

Treatments	Color parameters of cooked grains					
	*L**	*a**	*b**	*C**	*h°*	*ΔE**
CONV-Whole	48.04 ± 0.47^{c}	2.75 ± 0.42^{a}	10.44 ± 0.79^{b}	10.80 ± 0.86^{ab}	75.32 ± 1.26^{d}	0.49 ± 0.09
OH-Whole	48.36 ± 0.23^{c}	2.43 ± 0.12^{b}	10.26 ± 0.26^{b}	10.55 ± 0.27^{ac}	76.68 ± 0.40^{c}	
CONV-Dehulled	53.88 ± 0.63^{b}	1.50 ± 0.02^{c}	11.38 ± 0.36^{a}	11.48 ± 0.35^{a}	82.47 ± 0.31^{b}	3.07 ± 0.79
OH-Dehulled	56.70 ± 0.33^{a}	1.04 ± 0.27^{d}	10.31 ± 1.12^{b}	10.36 ± 1.14^{bc}	84.31 ± 0.9^{a}	

Different letters in the same column indicate significant differences between samples ($p < 0.05$).

There are no previous reports in the literature regarding color parameters of pearl millet grains cooked by the OH process; however there are a few studies in the literature concerning the color parameters of CONV cooked pearl millet grains. Yadav et al.(2012) reported for whole and decorticated pearl millet CONV cooked grains, values of *L**, *a**, *b** between 78.9-78, 1.39-1.62 and 12.9-11.9, respectively. Siroha & Sandhu (2017) evaluated the effect of CONV cooking (10 min) on 6 species of pearl millet and observed values of *L**, *a** and *b** ranging from 75.5-83.5, 0.07-0.96 and 9.2-12, respectively. For CONV cooked dehulled finger millet, Dharmaraj et al. (2014) found *L**, *a** and *b**, values of 40.4, 9.4 and 20.9, respectively. Thus the coloring of the grains varies according to the species, cooking time and decortication process. Color is an important attribute of quality and strictly related to the acceptability of the product. Therefore, a study correlating the effect of grain color parameters of cooked millet on acceptability is of great importance for the commercialization of this grain.

3.6 Functional properties of cooked pearl millet by OH and CONV cooking

3.6.1 Water absorption index(WAI) and Water solubility index (WSI)

Table 4shows the water absorption index (WAI) and water solubility index (WSI) of the cooked pearl millet flours. WAI is an indicator of the ability of flours to absorb water, and measures the volume occupied by starch and other components after swelling in excess water (SRIBURI *et al.,* 2000).WSI is often used as an indicator of starch conversion into small molecules driven by the application of shearing and heat. The results showed that the WAI and WSI values of cooked (OH and CONV) whole and decorticated flours did not show significant difference between them ($p>0.05$).These results indicate that the presence or absence of the pericarp (fibers, protein and among other compounds) did not affect WSI or WAI. Moreover, the electric field did not result in any additional non-thermal effects on the starch pearl millet flour.

The WAI value of the OH-whole and OH-Decorticated grains was 3.39g/g and 3.47g/g, respectively. Similar values of WAI have been reported for pearl millet grains in recent literature. Yadav et al. (2012) reported a WAI of 2.97g/g in pearl millet flours obtained from grains cooked in an autoclave for 25min. Abdalla &Mustafa (2014) reported a WAI of 3.62g/g and 4.14g/g in flours obtained by popped pearl millet and extruded decorticated pearl millet grains. Akinola et al. (2017) reported a WAI of 3.19g/g in flours obtained from malted grains of pearl millet.

The WSI of the OH-Whole and OH-Decorticated flours was 3.01g/100g and 2.44g/100g, respectively. These results were lower than those found in other studies for processed pearl millet flours. Yadav et al. (2012) reported a WSI of 9.99 g/100g in pearl millet flours from grains cooked in an autoclave for 25min. Akinola et al. (2017) reported a WSI of 11.27 g/100g in flour of decorticated pearl millet grains, previously obtained by hydration of the grains for 18h at 50ºC. Krishnan et al. (2011) reported a WSI of 3.8g/100g in finger millet flour obtained by cooking (98ºC for 30 min), while Robin et al. (2015) reported a WSI of 4.1g/100gin extruded proso millet flour.

3.6.2 Rapid Visco Analyzer (RVA)

The RVA profile is an important index for cooking quality because it reflects the degree of starch conversion (BECKER *et al.,* 2001). The pasting properties of cooked pearl millet grains are shown in **Table 4**. The results confirm that the viscosity of the samples is dependent on the type of processing applied to the grains. Whole grains in both treatments showed significantly lower viscosity values than the decorticated grains ($p < 0.05$). The low viscosity reading of flours from cooked whole grains was mainly due to the lower proportion of starch molecules present in the whole grains when compared to decorticated grains. As starch granules are mainly located in the endosperm of the grain, its content is proportionately higher when the pericarp is removed (HAMA, 2011). Furthermore, the presence of the pericarp is an effective barrier to grain hydration and helps to reduce the breakdown of the starch structure. The pasting temperature of the whole and decorticated grains, cooked by both treatments (OH and CONV) did not show any significant difference ($p > 0.05$). However, the millet grains cooked by both methods had a low initial pasting temperature. This finding differs from those reported by Gull et al. (2015) who found that the pasting temperature of pearl millet was89.6 ºC and finger millet was74.3 ºC. Pasting properties (initial viscosity at 25 ºC, peak viscosity (95 ºC) and break down) of the OH-Whole, did not show any significant difference to the CONV-Whole ($p > 0.05$). However, on comparing OH-Decorticated with CONV-Decorticated, only the breakdown was not significant ($p > 0.05$).

Cooked pearl millet grains by both treatments had peak viscosity values ranging from 98.6 to 170 cP (**Table 4**). Decorticated grain flours showed higher viscosity values than whole grain flours which may be attributed to its higher starch content as the pericarp was removed increasing the starch ratio. In addition, although not analyzed, whole grains may have higher lipids content than decorticated grains, leading to a reduction in viscosity (WANG & SASTRY, 1997). OH-Decorticated grains showed a lower peak viscosity value than CONV-Decorticated grains. This result is possibly due to the electric field that promotes a smaller alteration in the starch, a fact also proven by grain texture and yield analysis.

Different pasting properties between CONV and OH might be due to the different cooking mechanisms. OH provides electrical resistance heating when an alternating current is passed through an electrically conducting food product. However, the electrical conductivity(σ) decreases with high degrees of starch gelatinization (WANG &SASTRY, 1997). **Fig. 2** shows that a reduction of electrical conductivity on decorticated grains (15-20 min) and whole grains (25-30 min) may indicate the starting range of starch gelatinization. In other words, this constant decay of the electrical conductivity can be a result of starch gelatinization, as the formation of a three-dimensional starch damaged-water network occurs, promoting lack of water mobility. Therefore, by reading the reduction of the passage of the electric current through a starchy food, OH may be used as an alternative for rapid evaluation of starch gelatinization temperature as proposed by Wong et al. (2011).

The viscosity of all samples increased during the cooling cycle. Setback viscosity measures retrogradation of starch molecules, primarily amylose molecules that are prone to re-associate during cooling (JITTANIT *et al.,* 2017). Thus, cooked pearl millet samples with high setback viscosity indicate high tendency to retrograde into a thicker gel. CONV-Decorticated had the highest setback of 222.2 cP while CONV-Whole presented a lower value of 126.6 cP. This result shows that flours from decorticated grains, due to the absence of the pericarp and hence higher starch content, allow the higher number of amylose molecules available to form entanglements, thus increasing the retrogradation tendency.

Breakdown viscosity is regarded as the measurement of the degree of disintegration of starch granules and indicates the resistance of starch granules to heat and shearing. The CONV-Decorticated showed the highest value of breakdown viscosity, showing lower starch granule stability than CONV-Whole. Final viscosity indicates the ability of the starch to form a viscous paste during the cooling stage. Greater final viscosity was found for the CONV-Decorticated (365 cP); whereas the lowest value was for CONV-Whole (212 cP), which may be attributed to the presence of a higher content of starch molecules capable of increasing the viscosity, typical amylose behavior. The pasting property readings confirm that grain processing and cooking clearly affect the functionality and consequently provide a finger print that can be applied to understand the use of flours for other applications such as in cookies, cakes and pastas.

Pre-processed millet flours with lower viscosity may be preferred for preparing weaning foods for infants due to their limited ability to chew. In addition, another advantage of its low viscosity is in formulations where improved nutritional quality is desired without promoting an increase in viscosity. The ability of modified starchy pastes to change their viscosity or texture upon cooling or heating implies the type of industrial application that it can be used for. Lower setback values may also imply its use in canned and frozen food products.

Table 4: Functional properties of cooked pearl millet flours by conventional and OH cooking

	Whole		Decorticated	
	Conventional	Ohmic	Conventional	Ohmic
WSI (%)	3.16 ± 0.23^{a}	3.01 ± 0.32^{a}	3.45 ± 0.02^{a}	2.44 ± 0.28^{a}
WAI (g precipitate / g dry weight)	3.90 ± 0.15^{a}	3.39 ± 0.28^{a}	3.74 ± 0.08^{a}	3.47 ± 0.29^{a}
Pasting Temperature (ºC)	69.6 ± 0.05^{a}	69.6 ± 0.44^{a}	69.3 ± 0.47^{a}	69.7 ± 0.07^{a}
Initial viscosity at 25 ºC (cP)	26.8 ± 7.7^{bc}	39.5 ± 6.36^{a,b}	46.37 ± 9.11^{a}	24.33 ± 3.21^{c}
Peak viscosity (cP) at 95 ºC	98.6 ±7.5^{c}	116.3 ± 15.1^{c}	172.5 ± 4.9^{a}	135.5 ± 8.1^{b}
Minimal cooling viscosity (cP)	96.6 ± 6.5^{c}	122.5 ± 7.7^{b}	170.0 ± 8.4^{a}	134.0 ± 7.7^{b}
Maximum cooling viscosity (cP)	223.3 ±11.7^{d}	284.5 ± 16.2^{c}	392.5 ± 13.4^{a}	328.7 ± 10.0^{b}
Setback (ºC)	126.6 ± 7.6^{d}	159.3 ± 7.6^{c}	222.2 ± 4.9^{a}	191.7 ± 4.9^{b}
Breakdown (ºC)	2.00 ± 1.0^{b}	2.5 ± 0.7^{b}	6.0 ± 1.1^{a}	4.5 ± 2.1^{a,b}
Final viscosity (cP)	212.0± 17.3^{d}	253 ± 16.9^{c}	365 ± 14.4^{a}	294 ± 10.5^{b}

Values of WSI and WAI are mean standard deviation, n= 8 observations. Values of pasting properties are mean standard deviation, n= 5 observations. Different letters in the same row indicate significant differences between samples ($p < 0.05$).

4 CONCLUSION

Whole and decorticated pearl millet grains were cooked for 30 and 20 min, respectively, by the conventional open pan and ohmic methods. The cooking yield (%) of decorticated grains, cooked by both methods, did not differ. Ohmic heating (OH) did not result in softer grain texture than the conventional method.

The main impact on cooking was the pericarp rather than the heating method. Whole millet grain cooked by both methods did not present significant differences in color and texture, but decorticated millet grains cooked by the ohmic method resulted in harder grains with greater lightness than the conventionally cooked decorticated millet grains. Overall, OH could be a promising technology for cooking pearl millet grains, as it did not cause any negative affects on the quality attributes of the grains, and it is an environmental friendly technology and has high energy efficiency.

Further investigations are required in order to understand the effect of various parameters of ohmic heating, such as the electrical field and frequency, on the physical properties of pearl millet grains. Also, studies on the impacts of ohmic heating on preserving bioactive compounds and the sensory acceptance of pearl millet grains should be explored. Furthermore, investigations about the possible occurrence of electrochemical reactions and metal ion migration of OH cooked grains should also be evaluated for industrial applications.

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Conflict of interest

The authors declare to have no conflict of interest.

5 REFERENCES

ABDALLA, A., MUSTAFA, G.,. Some Physical and Functional Properties of Grain and Products of Pearl MilSome Physical and Functional Properties of Grain and Products of Pearl Millet (*Pennisetum glaucum* L.). **University of Kordofan Journal of Natural Resources and Environmental Studies** 1, 47-53, 2014.

AACC., 2000. Approved methods of the AACC (10th ed.). St. Paul, MN, USA: **American Association of Cereal Chemis**ts, 2000.

AKINOLA, S.A., BADEJO, A.A., OSUNDAHUNSI, O.F., EDEMA, M.O.,. Effect of preprocessing techniques on pearl millet flour and changes in technological properties. **Int. J. food Sci. Tech.** 52, 992-999, 2017.

ANDERSON, R., CONWAY, H., PEPLINSKI, A.,. Gelatinization of corn grits by roll cooking, extrusion cooking and steaming. **Starch-Stärke** 22, 130-135, 2970, 1970.

BECKER, A.; HILL, S.E.; MITCHELL, J.R.,. Milling - A further parameter affecting the rapid visco analyser (RVA) profile. **Cereal Chemistry**. 78 (2), 166-172, 2001.

BOURNE, M., 2002. Food texture and viscosity: concept and measurement. **Elsevier**.

CAPPATO, L. P., FERREIRA, M. V. S., GUIMARAES, J. B., COSTA, M. Q., CUNHA, R. L., OLIVEIRA, C. A. F., MERCALI, G. D., MARZACK, L. D. F., & CRUZ, A. G.. Ohmic heating in dairy processing: Relevant aspects for safety and quality. **Trends Food Science Technology.**.62, 104-112, 2017.

CHANDRASEKARA, A., NACZK, M., SHAHIDI, F.,. Effect of processing on the antioxidant activity of millet grains. **Food Chem**. 133, 1-9, 2012.

CHEN, F., YANG, C., LIU, L., LIU, T., WANG, Y., WANG, L., SHI, Y., CAMPANELLA, O.. Differences, Correlation of Compositions, Taste and Texture Characteristics of Rice from Heilongjiang China. **Journal Rice Research**. 5, 2017.

CIE. Commission International de l'Eclairage (CIE).Color Spaces, Color Difference Equations, Psychometric Color Terms, 3º edition, Publication nº15.3. 2004. Pages 17 -18. **Central Bureau of the CIE**, Paris, 2004.

CODEX ALIMENTARIUS COMMISSION, J.F.W.C.A., Organization, W.H., Programme, J.F.W.F.S., 2007. Cereals, Pulses, Legumes and Vegetable Proteins. **Food & Agriculture Org.CODEX Standart** 169-1989**.**Standard for whole and decorticated pearl millet grains.

COSTA, N. R., CAPPATO, L. P., FERREIRA, M. V. S., PIRES, R. P. S., MORAES, J., ESMERINO, E. A., CRUZ, A. G.. Ohmic Heating: A potential technology for sweet whey processing. **Food Research International**. 106, 771-779, 2018.

DHARMARAJ, U., RAVI, R., MALLESHI, N.. Cooking Characteristics and Sensory Qualities of Decorticated Finger Millet (*Eleusine coracana*). **Journal of culinary science & technology** 12, 215-228, 2014.

DIAS-MARTINS, A.M., PESSANHA, K.L., PACHECO, S., RODRIGUES, J.A. S., & CARVALHO, C.W. P.. Potential use of pearl millet (P*ennisetum glaucum* (L.) R. Br.) In Brazil: Food security, processing, health benefits and nutritional products. **Food Research International.**109, 175-186, 2018.

EYZAGUIRRE, R.Z., NIENALTOWSKA, K., DE JONG, L.E., HASENACK, B.B., NOUT, M.,.. Effect of food processing of pearl millet (*Pennisetum glaucum*) IKMP-5 on the level of phenolics, phytate, iron and zinc. **Journal of the Science of Food and Agricu**lture. 86, 1391-1398, 2006.

FARAHNAKY, A., KAMALI, E., GOLMAKANI, M. T., GAVAHIAN, M., MESBAHI, G., & MAJZOOBI, M.,. Effect of ohmic and microwave cooking on some bioactive compounds of kohlrabi, turnip, potato, and radish. **Journal of Food Measurement and Characterization**, 1-9, 2018.

FARAHNAKY, A., AZIZI, R., GAVAHIAN, M.,. Accelerated texture softening of some rootvegetables by ohmic heating. **Journal Food Engineering**,113(2), 275-280, 2012.

FRANCIS, F.J., CLYDESDALE, F.M.. Food colorimetry: theory and applications. 1975. A**VI Publishing Co. Inc**.

GAYTÁN-MARTÍNEZ, M., FIGUEROA, J., MORALES-SANCHEZ, E., VAZQUEZ-LANDAVERDE, P.A., MARTÍNEZ-FLORES, H.,. Physicochemical properties of masa and corn tortilla made by ohmic heating. **Afr. J. Biotechnol**. 10, 16028-16036, 2011.

GAVAHIAN, M., CHU, Y.-H., FARAHNAKY, A., Effects of ohmic and microwave cooking on textural softening and physical properties of rice. **Journal of Food Engineering**. 243, 114-124, 2019.

GAVAHIAN, M., CHU, Y.H., SASTRY, S.,. Extraction from Food and Natural Products by Moderate Electric Field: Mechanisms, Benefits, and Potential Industrial Applications. **Comprehensive Reviews in Food Science and Food Safe**ty.18, 1041-1052, 2018a.

GAVAHIAN, M., FARAHNAKY, A.,. Ohmic-assisted hydrodistillation technology: A review. **Trends in Food Science & Technology**.72, 153–161, 2018b.

GAVAHIAN, M., FARAHNAKY, A., JAVIDNIA, K., MAJZOOBI, M.,. Comparison of ohmic-assisted hydrodistillation with traditional hydrodistillation for the extraction of essential oils from *Thymus vulgaris* L. **Innovative Food Science & Emerging Technologies.** 14, 85-91, 2012.

GAVAHIAN, M., LEE, Y.-T., CHU, Y.-H.,. Ohmic-assisted hydrodistillation of citronella oil from Taiwanese citronella grass: Impacts on the essential oil and extraction medium. **Innovative Food Science & Emerging Technologies**. 48, 33-41, 2018c.

GULL, A., PRASAD, K., KUMAR, P.,. Effect of millet flours and carrot pomace on cooking qualities, color and texture of developed pasta. **Food Science and Technology**.63, 470-474, 2015.

HAMA, F., ICARD-VERNIÈRE, C., GUYOT, J.-P., PICQ, C., DIAWARA, B., MOUQUET-RIVIER, C.,. Changes in micro- and macronutrient composition of pearl millet and white sorghum during in field versus laboratory decorticated. **Journal of Cereal Sc**ience . 54, 425-433, 2011.

HITHAMANI, G., SRINIVASAN, K.,. Effect of domestic processing on the polyphenol content and bioaccessibility in finger millet (*Eleusine coracana*) and pearl millet (*Pennisetum glaucum*). **Food Chemistry**. 164, 55-62, 2014.

JITTANIT, W., KHUENPET, K., KAEWSRI, P., DUMRONGPONGPAIBOON, N., HAYAMIN, P., JANTARANGSRI, K.,. Ohmic heating for cooking rice: Electrical conductivity measurements, textural quality determination and energy analysis. **Innov.Food SciEmerg** *.42*, 16-24, 2017.

KAUR, N., SINGH, A.K.. Ohmic Heating: Concept and Applications—A Review. Crit. Rev. **Food Sci. Nutr**. 56, 2338-2351, 2016.

KRISHNAN, R., DHARMARAJ, U., SAI MANOHAR, R., MALLESHI, N.G.,. Quality characteristics of biscuits prepared from finger millet seed coat based composite flour**. Food Chemistry.** 129, 499-506, 2011.

LESTIENNE, I., BUISSON, M., LULLIEN-PELLERIN, V., PICQ, C., TRÈCHE, S.,. Losses of nutrients and anti-nutritional factors during abrasive decorticated of two pearl millet cultivars (*Pennisetum glaucum*). **Food Chem**. 100, 1316-1323, 2007.

MOHAPATRA, D., BAL, S.,. Cooking quality and instrumental textural attributes of cooked rice for different milling fractions. **J. Food Eng**. 73, 253-259, 2006.

MONTEIRO, M.A.M., MONTEIRO, A.J.A., COSTA, E.M..D., GARCIA, M.A.V.T.,. Classification of the rice (*Orysa sativa* L.) used in restaurants in Belo Horizonte-MG. **Brazilian Journal Food Technology.**19, 2016.

N'DRI, D., MAZZEO, T., ZAUPA, M., FERRACANE, R., FOGLIANO, V., PELLEGRINI, N., . Effect of cooking on the total antioxidant capacity and phenolic profile of some whole-meal African cereals. **Journal of the Science of Food and Agriculture** 93, 29-36, 2013.

PARAGINSKI, R.T., ZIEGLER, V., TALHAMENTO, A., ELIAS, M.C., DE OLIVEIRA, M., . Propriedades tecnológicas e de cocção em grãos de arroz condicionados em diferentes temperaturas antes da parboilização/Technological properties and cooking of rice grains conditioned at different temperatures before parboiling. **Braz JournalFood Tec**hnology. 17, 146, 2014.

PUSHPARAJ, F.S., UROOJ, A.,. Antioxidant activity in two pearl millet (*Pennisetum typhoideum*) cultivars as influenced by processing. **Antioxidant**s 3, 55-66, 2014.

ROBIN, F., THÉODULOZ, C., SRICHUWONG, S., Properties of extruded whole grain cereals and pseudocereals flours. **International Journal of Food Science & Technology.**50, 2152-2159, 2015.

SIROHA, A.K., SANDHU, K.S.,. Effect of heat processing on the antioxidant properties of pearl millet (*Pennisetum glaucum* L.) cultivars. **Journal of Food Measurement and Characterization.** 11, 872-878, 2017.

SHOBANA, S., MALLESHI, N.G.,. Preparation and functional properties of decorticated finger millet (*Eleusine coracana*). **Journal of Food Engineering** 79, 529-538, 2007.

SRIBURI, P., HILL. S. E.,. Extrusion of cassava starch with either variations in ascorbic acid concentration or pH. **International Journal of Food Science and Technology.** 35(2), 141-154, 2000.

TAYLOR, J.R.N.,. Millet Pearl: Overview, Encyclopedia of Food Grains (Second Edition). **Academic Press, Oxford**, pp. 190-198, 2016.

VEENA BHARATI, B., CHIMMAD, V., NAIK, R.K., SHANTHAKUMAR, G.,. Physico-chemical and nutritional studies in barnyard millet. Karnataka Journal of Agricultural Sciences 18, 2010.

Wang, W.-C., Sastry, S.K., 1997. Starch gelatinization in ohmic heating. **Journal of Food Engineering**. 34, 225-242, 1997.

WONG, L.-L., XU, Y.-W., LU, Z.-H., LI, L.-T.,. Correlation of electrical conductivity and thermal properties of native starch during ohmic heating. **International journal of food engineerin**g, 2011.

YADAV, D.N., KAUR, J., ANAND, T., SINGH, A.K.,. Storage stability and pasting properties of hydrothermally treated pearl millet flour. **International Journal Food Science Tec**hnology.47, 2532-2537, 2012.

YU, S., MA, Y., SUN, D.-W.,. Impact of amylose content on starch retrogradation and texture of cooked milled rice during storage. **Journal Cereal Science** 50, 139-144, 2009.

YETNEBERK, S., ROONEY, L.W., TAYLOR, J.R.,. Improving the quality of sorghum injera by decortication and compositing with tef. **Journal of the Science of Food and Agriculture** 85, 1252-1258, 2005.

CAPÍTULO III

EFFECT OF DECORTICATION, OPEN PAN, OHMIC HEATING AND EXTRUSION ON THE PHYSICOCHEMICAL AND FUNCTIONAL PROPERTIES OF PEARL MILLET

EFFECT OF DECORTICATION, GERMINATION, BOILING, OHMIC HEATING AND EXTRUSION ON THE PHYSICOCHEMICAL AND FUNCTIONAL PROPERTIES OF PEARL MILLET

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ARTIGO A SER ENVIADO PARA REVISTA **"LWT- Food Science and Tech."**

ABSTRACT

The effects of five processes (physical, biological and heating), on the particle size distribution, proximate composition, mineral content, absolute density, water absorption (WAI), solubility index (WSI) and pasting properties (RVA) of pearl millet (*Pennisetum glaucum* (L.) R. Br.) flours were investigated. Processed pearl millet flours have on average 65 % particle size between 355 µm and 255 µm. The chemical composition of raw flour, on average (wet basis), 62.5 % carbohydrate, 12.0 % protein, 5.6 % lipid, 8.2 % dietary fiber and 1.7 % minerals. Decortication promoted significant reduction of protein, lipids and dietary fiber content. Extrusion promoted reduction of the lipid content. However, germination, open pan and ohmic heating processes did not promote significant modification of any nutrient. Potassium, phosphorus and magnesium were minerals found in greater quantity in the pearl millet flours. Ohmic heating (OH) impacted the reduction of minerals. The processed flours presented bulk density values between 0.66 and 0.72 g/cm^3. The germinated flour had the less density. Flours obtained by extrusion and germination obtained the highest WSI values. The cooking processes (boiling and OH) promoted the highest WAI increase in pearl millet flour. Flours obtained by decortication obtained higher viscosity, higher breakdown in contrast, the sprouted flour obtained lower value of low viscosity and low setback. The decorticated and sprouted flours had a higher L * value while cooked flours. Thus, the results showed that processed flours can provide viable alternative ingredients for gluten free product formulation. In addition, it has shown that food processing can maintain nutrients and change functional characteristics on flours, thus promoting the use of it in various products. In this way, it can be said that processed flours of pearl millet are nutritious ingredients and of great potential for commercialization.

Keywords: gluten-free; cereals; composition; minerals;

1 INTRODUCTION

A major global trend in the food industry is the search for new nutritional ingredients for the development of gluten-free processed foods for celiacs, people with non-celiac gluten sensitivity (GNCS) and food-style adherents (NAQASH *et al.,* 2017). However, in recent years, another major challenge for the food industry has been to demystify the common idea that processed or ultraprocessed foods should be avoided because they may have low nutritional value and do not promote health benefits (ARES *et al.*, 2016).

Processed foods can be defined as those that undergo some sort of processing, in order to improve technological, microbiological and nutritional quality. According to Ares et al. (2016) for many consumers a processed or ultraprocessed food can be seen as negative because they are products that undergo multiple processing and are not beneficial to health. However, according to the Institute of Food Technology (ITAL) processed foods are safe products for consumption, they can be healthy for several aspects, add value. In addition, they increase demand for agricultural raw materials and should be encouraged because they impact on the country's economic and social development (ITAL, 2016). It is believed that increasing scientific information about the effects of different processing on the final quality of food can promote a better understanding of the population about processed foods.

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is a gluten-free cereal much consumed in African and Asian countries because of its low cost, protein and dietary fiber content and because it has excellent physiological characteristics of the crop as resistant to drought and high tolerance to high temperatures (BORA *et al*., 2019; DIAS-MARTINS *et al.,* 2018). Pearl millet flours can be obtained after milling and can be used in formulations of different products such as: gluten-free baked products, porridges, cookies, ready-to-eat snacks, non-dairy fermented beverages, biscuits, pastes and kibbeh (DIAS-MARTINS *et al.,* 2018; RAI *et al.,* 2014). However, the choice of flours with desirable characteristics for the development of a particular product is directly dependent on the type of pre-processing applied to the grains. Thus, the nutritional and functional characteristics of the flour, such as: nutrients content, particle size, density, water absorption capacity, solubility, viscosity and color will vary depending on the type of process applied.

Different processes can be applied to pearl millet grains such as physical process (decortication), biological process (germination) and heating process (cooking, ohmic heating and extrusion) (DIAS-MARTINS *et al.,* 2018). Decortication, promotes a 10 to 30%

reduction in grain thickness as a function of pericarp removal and part of the cereal germ (TAYLOR *et al.,* 2016). The application of this processing in the grains, can promote commercial advantages because it promotes modification of the color of the product and can promote reduction of the lipid content, increasing the shelf life the product. However, depending on the degree of decortication applied, nutritional reductions may occur in the final product (HAMA *et al.*, 2011).

Germination of the grains is a household practice commonly in African and Asia countries. In general, this process consists in three stages: immersion in water, germination and drying (DIAS-MARTINS *et al.,* 2018). The aiming to promote physico-chemical changes due a increase the enzymatic activity of phytases, glycosidases, amylases and proteases (OBADINA *et al.,* 2016). However, depending on the type of the cereal and chosen conditions (eg: T ° and humidity), different nutritional and functional characteristics can be obtained.

The cooking of grains is a traditional technique used to promote starch gelatinization, improve digestibility and reduce antinutritional factors. However, process conditions, such as: heat transfer mechanism and temperature used, may result in the reduction of water-soluble nutrients and changes in viscosity and color (N'DRI *et al.,* 2013). Ohmic heating (OH) has been reported as a promising emerging technology for cooking pearl millet (DIAS-MARTINS *et al.,* 2019). This process is more efficient than conventional cooking method, because it promotes an instantaneous and homogeneous heating in the grains by the conversion of electrical energy into thermal energy (Joule effect). However, depending on the electrical field and conductivity, different nutritional and functional characteristics can be obtained (DIAS-MARTINS *et al.*, 2019).

Thermoplastic extrusion is a sustainable process that uses high-temperature and short-time (HTST) along with shear to produce diversified like read-to-eat snacks, instant baby formula, dehydrated soups and instant flours. This technology can be applied to foods with the purpose of increasing shelf life due to the reduction of water activity, antinutritional factors, changes in texture, density, absorption, solubility, viscosity and color. However, the final quality of extruded product is directly dependent on the type of the raw material used and process variables such as moisture, temperature, screw type and rotation speed (VARGAS-SOLÓRZANO *et al.,* 2014).

The objective of this work was to evaluate the impact of varied pre-processing, such as physical, biological process and heating process in the nutritional and functional characteristics of pearl millet flours. This research intended to promote increase of knowledge and to demystify that all processes are negative to the nutritional and functional quality. In addition, it is believed that the limited number of researches on pearl millet products has not been contributing to include pearl millet into the diet of several western countries, such as Brazil. Use of pearl millet flours in Brazil has great potential because the consumption of gluten free cereals has been increased and the estimated cultivated area with pearl millet (*Pennisetum glaucum* (L.) R. Br.) is about 5 million ha (DIAS-MARTINS *et al.,* 2018). Therefore, the main purpose of this work it to share knowledge in order to increase the interest of the commercialization and consumption of this food in the Brazilian market.

2 MATERIAL AND METHODS

2.1 Native grains samples

Pearl millet grains (*Pennisetum glaucum* (L.) R. Br) cultivar BRS 1502, harvested in 2016 were produced and donated by Embrapa Milho e Sorgo (Sete Lagoas, Brazil). The grains were manually cleaned and stored in freezer at -18 ºC until processing. The samples were divided according to the final processing to be evaluated. All grains were processed had initial 10.5% moisture.

2.2 Processing applied in pearl millet grains

In order to examine the effect of processing on the physicochemical and functional properties, whole grains samples were submitted to different processing (physical, heat and biological, in duplicate, as described as following:

2.2.1 Physical processing

2.2.1.1 Decortication

Decortication was carried out with whole pearl millet grains in a mechanical abrasion rice dehusking machine (model MT-97, nº 3788-5, Suzuki, Brazil) for 10 min. The extraction rate used for the decorticated grains was of 87.8% according to methodology described in Dias Martins et al., (2019).

2.2.2 Biological processing

2.2.2.1 Germination

The whole grains with 99% of germination index were soaked in water (ratio 1:3 grain to water) for 4 h. At an interval of 1 h, water was changed in order to avoid fermentation, then drained. The grains were allowed to germinate a 8 doors fermentation cabinet (National Mfg. Co., Lincoln, USA) at controlled temperature (30º ± 2ºC) and relative humidity (and 90%) . After 48 h of germination, the grains were dried in fan oven at 30 °C for 24 h, until final moisture not greater than 12%.

2.2.3 Heat processing

2.2.3.1 Extrusion

The whole pearl millet grains with 10.5% moisture were milled in disc mill (DM) LM3100 (Perten Instruments, Huddinge, Sweden) at an opening aperture nº 2 that was fed into the feeding zone by a twin screw, loss-in-weight gravimetric feeder model GRMD15 (Schenck Process, Darmstadt, Germany) at rate of 10.8 kg/h and were monitored by Schenck Process Easy Serve software (Schenck Process, Darmstadt, Germany). The extrusion was performed using the twin screw extruder Clextral Evolum HT25 (Clextral Inc., Firminy, France), fitted with a four-holes die of equal diameter (3.8 mm), and at constant screw speed of 600 rpm and temperature profile, from feeding to die: 25, 30, 64, 100, 110, 110, 110, 110, 140 and 140 ºC. Extrusion conditions were selected on the basis of preliminary trials in order to obtain puffed extrudates. The extrudates were collected in placed in plastic trays and stored in plastic bags .

2.2.3.2 Wet cooking by Open Pan boiling and Ohmic Heating (OH)

Whole millet grains were cooked by method conventional (open pan boiling) and emerging (Ohmic heating) according to Dias Martins et al., (2019). Independent of the method used, all samples were cooking at 98 °C at ratio 1:2 (grain to water) for 30 min. The OH system consisted of a voltage source (Variac - 10140, São Paulo, Brazil), stainless steel electrodes, T-type (Copper/Constantan) thermocouples, digital multimeters (Icel - MD 6365, Manaus, Brazil) and a polymer tank (cooking chamber). The electrodes (15 x 9 cm length x height) were fixed to a Teflon® support, and the distance between them was 9.2 cm. The OH system applied an AC voltage at a fixed frequency (60 Hz). A data acquisition system (digital multimeters) was used to collect the signals of the alternating current, voltage and temperature at 20 s intervals. The electric field (V/cm) was calculated from the voltage data (V) in relation to the distance between the electrodes (9.2 cm). After cooking, the grains were dried in a fan oven at 30 °C for 24 h, until final moisture of 8%.

2.3 Preparation of the flours

All samples after processing were milled in two milling stages to gradually reduce their particle size: first stage it was used to disc mill LM3100 (Perten Instruments, Huddinge, Sweden) and after (second stage) was used to hammer mill LM3600 (Perten Instruments AB, Huddinge), with a 0.8 mm sieve aperture. The resulting flour of each processing was stored individually in polyethylene vacuumed package until further analysis.

2.4 Particle size distribution

Approximately 100 g were sieved in duplicate in ROTAP sieve shaker RX-29-10 (W.S. Tyler, St. Albans, USA) for 20 min. Seven screen sieve sizes (Newark, USA) were selected (425, 355, 300, 250, 212, 180 and 106 mm) and pan to obtain a normal-like particle size distribution.

2.5 Proximate composition analysis

The proximate composition of raw and processed grains were determined according to AOAC (2005) standards methods: moisture (method 935.29), protein (method 990.03, conversion factor of 6.25), fat (method 945.38), ash content (method 923.03). Carbohydrate content of each blend was determined by difference: % carbohydrate = 100 - (% moisture + % protein + % fat + % ash). The dietary fiber content was determined by the enzymatic method 985.29 of AOAC (2010) using the equipment Ankom model TDF Dietary Fiber Automated (Ankom Technology, New York, USA . Two replicates were performed for each analysis.

2.6 Determination of mineral element composition using ICP-OES

The composition of minerals was determinate by methods 999.10 and 990.28 to AOAC (2005). Two stages were carried out: acid mineralization of the sample via microwave and quantification of the elements by optical spectrometry. In the first stage of the analysis, digestion of the sample was carried out in XPress-type PFA® digestion tubes containing 6 ml of 69% purity nitric acid (Fluka, Trace SELECT®-Sigma-Aldrich) conditioned in cavity Microwave model MARS5 (CEM, North Caroline, USA) with power of 1600 W, temperature of 190 ° C for 20 minutes. The digested sample was transferred quantitatively to a 50 mL volumetric flask, the volume was made up with water ultrapure. The second step was the quantification of the minerals sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), manganese (Mn), iron (Fe), zinc (Zn), copper (Cu), phosphorus through nebulization of the samples to the Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES), model

Optima 2100DV (Perkin Elmer, Pennsylvania, USA). Two replicates were performed for each sample.

2.7 Bulk density

For bulk density determination, a cylinder of 50 ml graduated was filled with the sample of grain and flour and tapped twenty times. The excess flour was leveled off and the content was weighed. The bulk density (g/cm^3) was expressed as the sample weight per sample volume after tapping. Four replicates were performed for each sample.

2.8 Water absorption Index (WAI) and Water Solubility Indexes (WSI)

Water absorption index (WAI) and water solubility index (WAI) were determined by the methodology described by Anderson et al. (1970) with modifications. WAI and WSI of the cooked flours were determined in quadruplicate. Approximately 1 g of whole sample was weighed in falcon tubes containing 10 mL of distilled water and homogenized for 20 s in a vortex mixer. Then, in order to promote complete hydration, the tubes were placed in a water bath under agitation Dubnoff NT32 (BioVera, Rio de Janeiro, Brazil) for 30 min at 25 °C. Then, the tubes were centrifuged in a Universal 320R (Hettich, Tuttlingen, Germany) for 15 min at 7000 rpm. The supernatant was dried in a fan oven at 105 ºC until constant weight. The wet precipitated was to weight. The WSI and WAI were calculated according to equations reported in reported in Dias Martins et al., 2018. Eight replicates were performed for each sample.

2.9 Pasting properties

The pasting properties of the pearl millet cooked flours were analyzed using a Rapid Visco Analyzer (RVA) series 4 model (Newport Scientific PTY Ltd, Warriewood, Australia). Approximately, 3 g of cooked flours with particle sizes between 212 and 106 mm and moisture adjusted to 14 g of water/100 g were added to 25 g of distilled water. The temperature profile included initially mixing and holding the specimen with the paddles rotating at 160 rpm at 25 ºC for 2 min, heating to 95 °C (held for 3 min) and cooled to 25 °C, resulting in a total time of 20 min. The heating and cooling phases were performed with temperature gradients of 6 ºC/min. The values of the initial paste viscosity, maximum viscosity, final viscosity and setback (tendency of retrogradation) were expressed in cP.

2.10 Statistical analysis

Statistical analyses were performed using Excel and Statistic software 7.0 (Statsoft Inc., Tulsa, USA). The Fisher's means comparison test with a confidence level of 95% was used to compare the results.

3 RESULTS AND DISCUSSION

3.1 Effect of processing on particle size distribution

The particle size distribution is an important quality factor for the development of food products and directly influences the physical properties such as color, viscosity, density and texture of the final products (FAROOQ *et al.,* 2018; HIDALGO *et al.*, 2014; KERR e*t al.,* 2001). **Fig. 1** shows the particle size distribution of processed flours from pearl millet grains. The results revealed that the raw flour particles were coarser than the processed flours because they presented ~ 76 % with particle size between 425 µm and 355 µm. According to Codex Alimentarius Commission (2007), when at least 100 % of the pearl millet flours pass through the 500 µm sieve can be classified as fine flours. The processed flours have, on average, 46 % with particle size of 355 µm and 19.5% with particle size of 255 µm. In according with Nkama et al. (2015) the granulometry of 400 µm of pearl millet flour is considered indicated for preparation of Dakuwa, Nigeria traditional sweet. Sumathi *et al.* (2007) reported that pearl millet flour with size of 355 µm can be used together with chickpeas and other ingredients, for production of protein supplements for children.

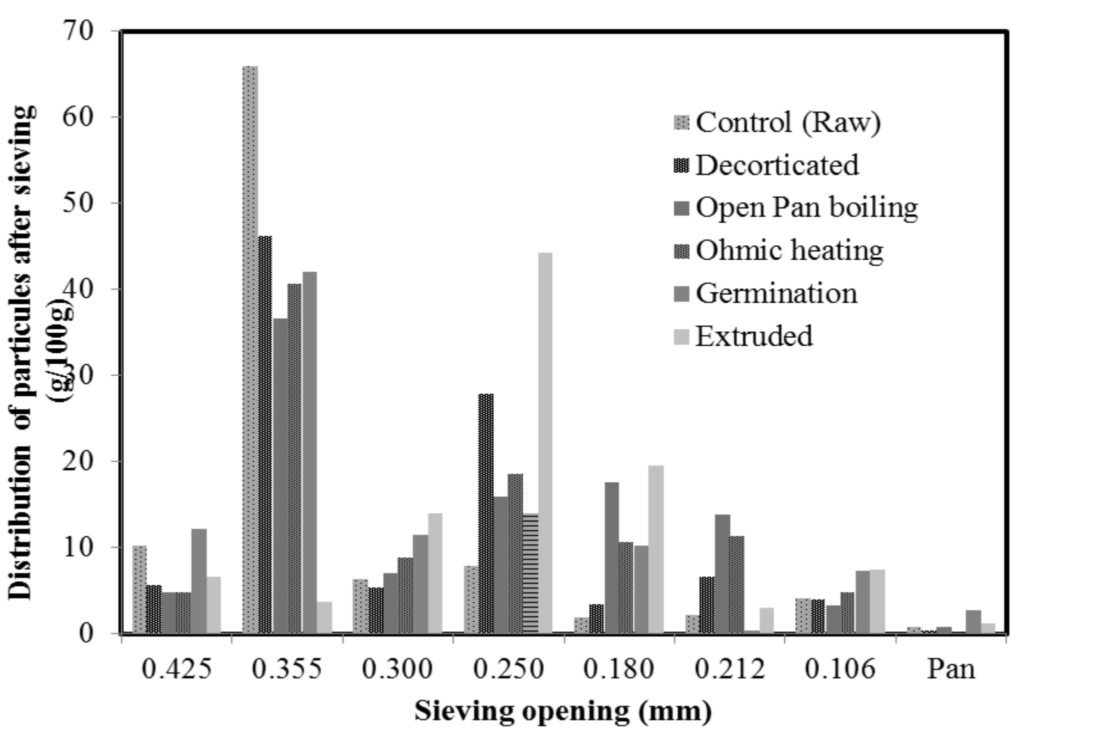

Figure 1: Particle size distribution of pearl millet flours: ( ) Control (Raw),; ( ) Decorticated; ( ) Open pan boiling; ( ) Ohmic Heating; ( ) Germination; ( ) Extruded.

In **Figure 1** shows that depending on the processing applied, the particle size distribution of pearl millet flours showed differences in quantities of fine and coarse particles ($p < 0.05$). When comparing the particle size of the raw flour with processed flours, it was observed, in general, that the processing increased the proportion of particles of reduced size of 250 µm to 106 µm ($p < 0.05$). By comparing cooked flours (open pan boiling and OH), similar results were observed for both processes.

The particle distribution of the extruded flours showed be more homogeneous, possibly because this process applies both heating and shearing simultaneously. It is well know that thermoplastic extrusion cause great texture modification. As starch is the main component in cereal grains, it is greatly damage depending how severe is the extrusion process. At screw speed of 600 rpm, it is expected great shear between both screws an barrel wall, particularly at the die, where reverse elements of the screws act breaking the starch granules and any other pearl millet components, such as insoluble fibers and proteins. As a consequence of this process, it was found higher amount of particles retained at 250 µm sieve, which were higher and significantly different from others processed flours. Besides that, the extrusion promoted a greater reduction of the water content of the product, which may affected the grain size distribution.. The low moisture of extrudates (**Fig. 1**), may have contributed for the homogeneous distribution of this extruded flour. In relation of sprouted flours, a larger proportion of particles with 425 µm of size were observed. Possibly, due to the presence of the radicles in the sprouted grains.

The decorticated flour had the second largest proportion of particles with a size of 250 µm. This may be due to the fact that decortication promotes the removal of bran containing larger particles such fiber and allows smaller endosperm particles are in greater proportion. Thus, the results showed of particle size distribution of the pearl millet grains pre - processed and milled in disc mills and sieve coupled with hammer of size 0.8 mm in diameter, have a grain size of ~ 300µm with variations depending on the process. The grain size of a flour can directly impact the functional properties such water absorption, solubility and viscosity of a product and the consumer's final acceptance, so the choice of processing should be important for product development (FAROOQ *et al.,* 2018b).

3.2 Effect of Processing on Proximate Composition

The proximate composition of pearl millet flours are presented in **Table 1**. Exception for decorticated flour, the results of others flours showed that, protein, lipid and dietary fiber were not significantly different from the raw flour ($p > 0.05$). The raw flour present higher protein, fat and total dietary fiber than other flours from gluten-free cereals such as: maize, rice and sorghum (DIAS-MARTINS *et al*., 2018). Thus, the processed flours, with exception of decorticated flour, could be labelled as source of fiber (> 3 g dietary fiber/50 g) and source of protein (> 6 g dietary fiber/50 g) (ANVISA, 2003 a,b ; ANVISA, 2012).

The average of moisture content was 11%. This result is in accordance with the quality standards described by the Codex Alimentarius Commission (2007) which recommends a maximum of 13% m/m of moisture content for pearl millet grains. The extruded flour was the only one that significantly differed the moisture content of the other flours because the original water content prior to process was low and also heat and shear lead to further water reduction. The chemical composition of raw pearl millet flour, on average (wet basis), were: 62.5 % carbohydrate, 12.0 % protein, 5.6 % lipid, 8.2 % dietary fiber and 1.7 % minerals. These values were similar reported by Dias-Martins *et al*. (2018). The carbohydrate content of processed flours ranged from 60 % to 68 %. This variation occured because the carbohydrates were calculated by difference.

The protein content of pearl millet flours ranged from 11.4 to 12.8 g/100 g (**Table 1**). Decortication promoted a significant reduction of 5% of the protein content compared to raw flours, which can be attributed to the removal of the hull (12.2% degree decortication) that removed some of the protein-rich aleurone cell (HAMA *et al.,* 2011).

The protein values found were similar to those reported by Sumathi et al. (2007) for decorticated flours (11.2 g/100 g) and higher, when compared to extruded flours (9.6 g / 100 g). Lower protein values (11.84 %) were reported in raw flours by Thilagavathi et al. (2015) and Bora et al. (2019) which reported values ranging from 8.1 to 9.1 g/100g (wet basis). The protein value of the sprouted flour was marginally significant (weak effect) when compared to the raw flour ($p < 0.06$). (AKINOLA *et al.,* 2017; OBADINA *et al.,*2016) reported that sprouted pearl millet flour for 48 h had increased protein content by 17% and 28%, respectively, when compared to raw flour. However, according to Pushparaj & Urooj, (2011) germination did not significant affect the protein content of pearl millet flours.

Table 1: Proximate composition pearl millet flours*

Analyses	Control (Raw)	Decorticated	Germination	Open Pan boiling	Ohmic heating	Extruded
Moisture (g/100g)	9.85 ± 1.54[a]	10.64 ± 0.26[a]	8.96 ± 0.60[a]	8.99 ± 0.93[a]	10.08 ± 0.22[a]	6.60 ± 0.04[b]
Macronutrients (g/100g)						
Carbohydrates	62.56 ± 0.24[b]	68.15 ± 0.6[a]	67.47 ± 0.02[a]	62.39 ± 3.2[b]	61.48 ± 0.5[b]	68.15 ± 0.3[a]
Protein **	12.01 ± 0.17[a]	11.47 ± 0.22[b]	12.87 ± 0.17[a]	12.12 ± 0.01[a]	12.69 ± 0.88[a]	12.62 ±0.17 [a]
Lipid	5.63 ± 0.38[a]	1.85 ± 0.10[c]	4.75 ± 0.77[a]	5.46 ± 0.22[a]	4.79 ± 0.15[a]	2.83 ± 0.29[b]
Total dietary fiber	8.24 ± 1.04[a]	4.82 ± 1.80[b]	8.45 ± 0.38[a]	8.94 ± 1.69[a]	8.19 ± 0.18[a]	8.97 ± 0.16[a]
Ash	1.71 ± 0.54[ac]	1.32 ± 0.01[bcd]	1.33 ± 0.06 [bcd]	2.08 ± 0.36[a]	1.67 ± 0.17[ab]	1.53 ±0.01 [ad]
Micronutrients (mg/kg)						
Potassium (K)	3702 ± 98.04 [ab]	3151± 291.16[bc]	3310± 18.60 [ac]	3101± 575.01 [bc]	2019±68.87 [d]	3871± 34.67 [a]
Magnesium (Mg)	1296 ± 64.02 [ac]	1164± 134.03 [bcd]	1314± 25.32 [ab]	1157± 66.65 [bcd]	1017± 54.61 [d]	1351± 12.72 [a]
Calcium (Ca)	151 ± 16.55[b]	103 ± 5.71[c]	167 ± 10.04[b]	149 ± 4.61[b]	111 ± 9.43[c]	190 ± 2.04[a]
Manganese (Mn)	13.32 ± 0.14[a]	8.91 ± 1.20[c]	13.93 ± 0.37[a]	12.45 ± 0.78 [ab]	11.51 ± 0.73[b]	13.84 ± 0.05[a]
Iron (Fe)	57.84 ± 9.11[a]	31.53 ± 2.70[a]	50.56 ± 0.97[a]	48.37 ± 6.24[a]	64.12 ± 1.58[a]	54.31 ± 0.28[a]
Zinc (Zn)	41.28 ± 7.22 [a]	31.86 ± 5.33 [a]	36.27 ± 4.84 [a]	39.85 ± 6.41[a]	31.91 ± 4.27[a]	35.52 ± 3.86[a]
Copper (Cu)	4.95 ± 0.23[a b]	4.19 ± 0.38[c]	4.83 ± 0.07[b]	4.47 ± 0.24 [bc]	4.11 ± 0.24[c]	5.78 ± 0.12[a]
Phosphorus (P)	3476 ± 101.2[a]	3195 ± 475.14[ab]	3431 ± 69.01[ab]	3224 ± 281.10[ab]	2876 ± 164.01[b]	3654 ± 9.05[a]

*Means followed by different superscripts along the rows are significantly ($p<0.05$) different

** Protein = N x 6.25

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The fat content of flours ranged between 1.85 and 5.6 g/100 g (**Table 1**). The germ of pearl millet grains are rich in lipids and can be promote negative effects on the stability of flours, because they are more susceptible to oxidation (DIAS-MARTINS *et al*., 2019). Similar results of fat content in raw flour were reported by (OBADINA *et al., 2*016; PUSHPARAJ & UROOJ, 2011; THILAGAVATHI *et al.*, 2015) which found 5.1 g/100 g, 4.3 g/100 g and 6.34 g/100 g, respectively. The results of decorticated (1.85 g/100 g) and extruded (2.83 g/100 g) flours showed that they can be alternative processes to increase the shelf life of flours, since they significantly reduced lipid content when compared to raw flour (5.6 g/100 g). Decortication and extrusion process promoted reduction of the lipid content of 67% and 50%, respectively. Decortication promotes the removal of aleurone layer, bran and germ partially (JHA *et al.*, 2015). However, because the germ are embedded in the endosperm, variations in the final lipid content of decorticated grains can be found (DIAS-MARTINS *et al.,*. 2019). Hama et al. (2011) did not observe a significant reduction of the lipid content after decorticating pearl millet grains (88% of extract rate), also extraction rate was similar to that performed in this study. In relation to extruded flour, the reduction of the lipid content may have occurred due to lipid oxidation through of high temperature (> 140 ºC) and the presence of pro-oxidants present by the extrusion process. This result was similar to Sumathi et al. (2007), which reported fat content of 2.7 % in extruded pearl millet flour. However, it can be said that extruded flours may also have a higher shelf life than flours processed by boiling, ohmic heating and germination because in addition one of having lower lipid content than others. Besides extrusion processing can also promote greater inactivation of lipases that are responsible for lipid degradation during storage.

The total dietary fiber (TDF) content of the pearl millet flours ranged between 4.82 and 8.19 g/100g (**Table 1**). The use of 50 g of the pearl millet flours (process or not) would provide 10% to 13% of the Recommended Daily Intake (RDA) of dietary fiber, according to ANVISA, (2003a). Omoba *et al*. (2015) also reported that the use of pearl millet flours should be used for biscuits because they have high fiber content and shows a potential as a supplementary food for school-age children in nutritionally at risk communities in Africa. The TDF found for raw pearl millet flour in this research was 8.24 g/100g. These values were similar by Suma & Urooj, 2014 that reported value of (5.1g/100g). However, this value was higher that to those reported by Dias-Martins *et al.* (2019), 7.8g/100g and lower to that reported by Pushparaj and Urooj, (2011), who found 12.6g/100g of TBF in raw pearl millet flours.

With exception of decorticated flour, the TDF results of processed flours did not differ ($p > 0.05$) from raw flour. Decortication promoted a significant reduction of ~ 41% in fiber content when compared to raw flour. Different results can be found in the literature. Pushparaj & Urooj (2011) did not observe a significant difference in the fiber content of pearl millet flours processed by: boiling (30 min), pressure cooking (10 min), germination (72 h) or roasting (200 °C for 15 min), when compared to raw flour. According to the authors, only the decorticated flour promoted a significant reduction in fiber content, the same conclusion obtained by the present study. However, different results were obtained by Sharma et al. (2018) which reported that the germination of foxtail millet grains promoted a 58% increase in dietary fiber content, due to enzymatic reaction occurring during germination.

The ash content of the millet flours ranged between 1.32 and 2.08 g/100g (**Table 1**). There was no significant difference between the processed flours and the raw flour.

3.3 Effect of Processing on Mineral Content

Regarding mineral composition, potassium, phosphorus and magnesium were found in considerable quantities in pearl millet flours, while calcium, iron, zinc and manganese were in much lower quantities (**Table 1**). These results are in agreement with Dias-Martins *et al.,* (2019). OH significantly reduced the mineral content of the flour (45% K, 21% Mg, 26% Ca, 17% Cu and 17% of P). This result may be related to the electrical conductivity of the system. The electrical conductivity can be considered as a measure of the electron flow. Thus, because they are good conductors of electricity, the minerals may have migrated from the grains to the forming water during cooking, due to the electrical conductivity being greater in the liquid (water) than in the solid (grains) (ZAREIFARD *et al,* 2014).

Although the decortication process promoted apparent reduction of minerals (**Table 1**), only the Mn^{+2} and Cu^{+2} contents differed significantly ($p < 0.05$) from the raw flour. In relation of the germination process, any significant effect on the mineral content was observed when compared to raw flour ($p > 0.05$). The only minerals that were not reduced by any processes were iron and zinc ($p > 0.05$). The potassium, phosphorus and calcium contents of raw pearl millet flour were similar to reported by Obadina *et al.* (2016). However, the values obtained for phosphorus were much higher than those found by Oshodi, (1999) and Thilagavathi *et al.,* (2015) who reported values of 99- 256 mg/kg of P in raw pearl millet flours. Variations in phosphorus content can be attributed to different genotypes, genetic conditions and cultivation forms and soil fertilization.

The iron and zinc are limited minerals in pearl millet grains and can be reduced depending on the applied process (TIWARI *et al.,* 2014). Oshodi (1999) reported values similar of Fe (55 mg/kg) and Zn (45 mg/kg) in raw pearl millet flours. Tiwari *et al.* (2013) reported that decortication for 10 min of pearl millet grains significantly reduced zinc (27.8 mg/kg) and iron (66.5 mg/kg) content. The results obtained from the present research, showed that the processing of decortication did not negatively impact the content of these minerals (**Table 1**). This statement is in agreement with Omoba et al. (2015), who reported that biscuits produced with pearl millet flour contain substantial levels of iron and zinc. The results showed that the iron content in the processed pearl millet flours provide 6 % to 10 % of the Recommended Daily Intake (RDA), according to ANVISA, 2003a. In addition, magnesium, zinc and phosphorus contents of millet flours would make a significant contribution (11 to 15%) to the RDA. However, according to FDA, potassium would only contribute with 3% to daily values recommending per day for Americans 4 years of age or older.

Thus, it can be observed that regardless of the type of processing applied on the pearl millet grains, the resulting flours present great nutritional potential and its commercialization should be stimulated. However, new research must be carried out to verify if applied processes, especially germination, promotes changes in protein and starch digestibility

3.4 Effect of processing on functional properties

Table 2 shows the functional properties of all pearl millet flours.

3.4.1 Bulk density

Bulk density not taking into account the porosity of the material, that is, the mass of the sample per unit volume of the sample, including the internal volume of pores. Density is important physical property of flours because it plays an important role in storage, transportation and indicates the volume to be filled in the packaging (YADAV *et al.,* 2012).

Flours from processed pearl millet grains presented values between 0.66 and 0.72 g/cm^3. The bulk density obtained from this study showed that flour raw has significantly ($p < 0.05$) higher density (0.72 g/cm^3), while the lowest value (0.66 g/cm^3) of bulk density was recorded for germinated flour. The germinated flour had the less density (0.66 g/cm^3), which means that it has the less mass compaction and, when stored in a package, will occupy highest volume than raw flour, for example. Germination processes were observed to cause a decrease in bulk density, as this processes have soften the grains, leading to a breakdown of complex structures (carbohydrates), to smaller units caused by the actions of enzymes. The germinated flour had the lowest density (0.66 g/cm^3), which means that it has the highest mass compaction and, when stored in a package, will occupy less volume than extruded flour, for example

3.4.2 Water absorption index (WAI) and water solubility index (WSI)

The water absorption capacity plays an important role in the development of food and its value is directly dependent on the modified starch and dietary fiber present (DEVISETTI *et al.,* 2014). The pearl millet raw and decorticated flours showed the lowest WAI values. This was expected since the WAI of these flours presented larger particle size (**Table 1**) and the starch of these samples did not undergo any modifications. The comparing with raw flour decortication process reduced significantly ($p<0.05$) the absorption of water possibly due to the loss of fiber, which has the ability to bind and hold water (**Table 2**). These results are in agreement with research Devisetti *et al.* (2014) who reported that flours obtained from decorticated grains of foxtail millet and proso millet had lower WAI than the whole flours of these cereals. According to the authors, WAI of the whole and polished flour of foxtail and millet proso varied from 1.43 g/g to 1.67 g/g and 1.49 g/g to 1.30 g/g respectively, values slightly lower than that found in raw and decorticated flours of the present study.

The germination promoted a slight increase of 10% in WAI when compared to raw flour ($p < 0.05$), possibly due to the action of the amylases on the starch granules in the grain. Some research observed a similar trend (ADEBIYI et al., 2016; COULIBALY *et al.*, 2012; SHARMA *et al.,* 2018). Adebiyi *et al.* (2016) and Coulibaly *et al.* (2012) reported that germination of pearl millet grains promoted a significant increase of 20% and 71% in WAI, respectively. Sharma *et al.* (2018) reported that germination of foxtail millet promoted a 6% increase in WAI. According to the authors, this modification could be attributed to changes in protein quality and the production of hydrophilic components such as sugars and protein during germination. However, this trend was not observed by Akinola *et al.* (2017) which reported that germination of pearl millet grains reduced WAI by 12 %. According to James et al. (2018), sprouted flour which has low WAI (~ 2.16 g/g) is desirable for making thinner gruels with high caloric density per unit volume. These characteristics increase the absorption of nutrients by infants and reduces microbial activities due to the low water activity extending the shelf life of the product.

The flours that presented the highest WAI were obtained by extrusion, boiling and OH processes, respectively (**Table 2).** When compared all processes, the extrusion promoted the highest WAI value (4.12 g/g). (JAFARI *et al.*, 2017; KHARAT *et al.,* 2018) observed a similar trend. This result is because to these flours had a smaller particle size **(Table 1)** due the combined effect of high temperature with shear, which results in higher proportion of damaged starch that favored the better dispersion of the soluble polysaccharide in water, increasing WAI. WAI values of extruded pearl millet flour were higher than the WAI values obtained by Kharat et al. (2018) which reported 3.37 g/g in extruded flour processed at 15% moisture, 130 ºC temperature and screw speed of 350 rpm. However, these differences were attributed to the process conditions. In this research, the extrusion conditions were 11% moisture, 140 ºC and screw speed of 600 rpm. Changes in these parameters can directly impact the WAI of the final products (KHARAT *et al.,* 2018). In addition, comparing the WAI results of pearl millet flours with the literature, it can be said that flours have great potential to be used since they resemble values found in blends of wheat flour and rice (1.3 to 1.7 g / g) and on vegetable flours such as chickpea (1.19 g / g), lentil meal (1.33 g / g), black eye bean (1.12 g / g) (CHANDRA *et al.,* 2015; DU *et al.,* 2014).

The WSI values varied from 3.01 to 10.98 % are shown in **Table 2**. The minimum WSI value was observed for raw flour cooked by boiling and ohmic heating. It is can be due to some complexation of starch with proteins or lipids that can reduce the WSI value in pearl millet flours because of a decrease in the soluble parts within starch molecules (KRAITHONG *et al.,* 2018). WSI results were higher for extruded sample (10.98%) followed by germinated flours (9.05%). A high solubility index indicates an extensive starch conversion to lower molecular weight compounds (JAFARI *et al.,* 2017). The WSI of the extruded and germinated flours were high because in both processes the granule structure of the starch was broken, which consequently increased the exposure of hydroxyl groups favoring their dispersion in water (FAROOQ *et al.,* 2018). In the extrusion process, this effect is due to the combination of high temperature and shear on the starch granules, whereas in germination is due to the formation of lower molecular weight molecules obtained from the breakdown of large molecules by the activity of amylases and proteases (GONG *et al.,* 2018).

Several studies have reported increased solubility of cereal flours after extrusion and germination (GONG *et al.*, 2018; GULATI *et al.,* 2016; JAFARI *et al.,* 2017). Gong et al. (2018) observed an increased when whole corn flours was treated by germination or extrusion, furthermore, the synergistic effect of germination and extrusion was more pronounced. Jafari et al. (2017), reported the solubility increased significantly in extruded sorghum flours and this increase was directly related to the increase in temperature used in the extruder. Gulati *et al.* (2016) also reported that extruded millet flours had values ranging from 3.7 to 8.1% and the combined effect of screw speed, temperature and humidity significantly affected WAI.

Due to their high solubility, both the extruded and the sprouted flour are ingredients with potential to be used as ingredients for vegetable drinks. However, despite of having similar solubility, the extruded flour has certain advantages, due the lower lipid content **(Table 2**), which may result in products with longer shelf life and, consequently, higher value added. The result indicates that germination and extrusion processing of pearl millet grains significantly ($p< 0.05$) influenced the increase in WAI and WSI. In addition, the above results show that pearl millet flours have potential use in the formulations in baking products and vegetable beverages.

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Table 2: Functional properties of the pearl millet flours

Analyses	Control (Raw)	Decorticated	Germination	Open Pan boiling	Ohmic heating	Extrusion
Bulk density (g/cm^3)	0.728 ± 0.015 ^{a}	0.695 ± 0.01 ^{b}	0.664 ± 0.02 ^{c}	0.709 ±0.06 ^{b}	0.711 ±0.01 ^{b}	0.699 ± 0.04 ^{b}
WAI (g /g)	1.96 ±0.11 ^{d}	1.87 ± 0.10 ^{e}	2.16 ± 0.01 ^{c}	3.90 ± 0.15 ^{a**}	3.39 ± 0.28 $^{a\,**}$	4.12 ± 0.10 ^{a}
WSI (%)	5.07 ± 0.27 ^{c}	4.7 ± 0.07^{cd}	9.05 ± 1.07 ^{b}	3.16 ± 0.23$^{d\,**}$	3.01 ± 0.32 $^{d\,**}$	10.98±1.13 ^{a}
Initial viscosity at 25 ºC (cP)	36.32 ± 14.74 ^{b}	34.32 ± 3.15^{b}	42.92 ± 1.65 ^{b}	26.8 ± 7.7 $^{b\,**}$	39.5 ± 6.36 $^{b\,**}$	159.02 ± 3.3 ^{a}
Peak viscosity (cp) at 95 ºC	644.25 ± 100.5 ^{a}	793.50 ± 174.6^{a}	48.25 ± 4.59 ^{c}	98.6 ±7.5 $^{b\,**}$	116.3 ± 15.1 $^{b\,**}$	105.25 ± 0.35 ^{b}
Minimal cooling viscosity (cP)	399 ± 29.68 ^{a}	450 ± 140.7^{a}	33.50 ± 2.82 ^{b}	96.6 ± 6.5 $^{b\,**}$	122.5 ± 7.7 $^{b\,**}$	68.25 ± 3.88 ^{b}
Maximum cooling viscosity (cP)	1642.8 ± 368.04 ^{a}	2070.0 ± 508.40^{a}	37.25 ± 17.32 ^{c}	223.3 ±11.7 $^{b\,**}$	284.5 ± 16.2 $^{b\,**}$	155.25 ± 1.76 ^{b}
Setback (ºC)	1243.8 ± 338.35 ^{a}	1620 ± 367.69^{a}	21.50 ± 10.60 ^{c}	126.6 ± 7.6 $^{b\,**}$	159.3 ± 7.6 $^{b\,**}$	87 ± 5.65 ^{b}
Breakdown (ºC)	245.25 ± 70.35 ^{a}	343.50 ± 33.94^{a}	20.6 ± 5.65 ^{b}	2.00 ± 1.0 $^{c\,**}$	2.5 ± 0.7 $^{c\,**}$	37.9 ± 4.24 ^{b}
Final viscosity (cP)	1502.5 ± 195.8 ^{b}	1860 ± 258.0^{a}	38.5 ± 6.36 ^{d}	212.0± 17.3 $^{c\,**}$	199.2 ± 8.83$^{c\,**}$	149.5 ± 2.12 ^{c}

Values of WSI and WAI are mean standard deviation, n= 8 observations. Values of pasting properties are mean standard deviation, n= 5 observations.

*Results are mean standard deviation, n= 4 observations. ** Values found in Dias Martins *et al.,* (2019).

3.4.3 Pasting properties

Pasting characteristics is one of the most important properties for food development, directly affecting the physical, chemical and sensorial characteristics of the final product (JAMES *et al.*, 2018). When the starch is heated in excess of water there is disorder of the amylose and amylopectin molecules, promoting an irreversible swelling of the starch and consequently an increase in viscosity. However, the viscosity values are directly dependent on the starch ratio, degree of crystallinity and extent of the amylose chain and protein content (JAMES *et al.,* 2018; KHARAT *et al.,* 2018). The Rapid Visco Analyzer (RVA) of the pearl millet flours are presented in **Table 2**. The results confirm that the viscosity of the flours is dependent on the type of processing applied to the grains. The maximum values of pasting properties were observed for raw and decorticated flours and the lower value was obtained for sprouted flour.

Peak viscosity indicates the point at which gelatinized starch reaches its maximum viscosity during heating in water. Raw and decorticated pearl millet flours differed significantly from other flours ($p < 0.05$) and had the highest values of peak viscosity (644cP to 793 cP). No significant difference was observed in relation to the peak viscosity between the decorticated and raw flour, although the protein content of the decorticated flour was lower (**Table 2**). Peak viscosity of the raw and decorticated flours were higher because the starch present in these samples did not undergo considerable modifications and mostly kept its crystalline structure or integrity, hence able to swell as a resulting of maximum water absorptionduring the gelatinization process. Similar results was obtained by Gull et al. (2016) which found a peak viscosity value of 429 cP for raw pearl millet flour. However, Kharat et al. (2018) found that raw pearl millet flours showed peak viscosity value of 1950 cP.

Peak viscosity of the flours obtained by extrusion, boiling and OH processes did not differ among themselves ($p > 0.05$) and their values ranged from 98 to 116 cP. The heating processes promoted a reduction of 83 % to 90 % on peak of viscosity and in the maximum cooling viscosity, when compared to the values obtained in the raw flour (**Table 2**). Patel (2015) reported that extrusion process promoted a 67 % reduction in peak of viscosity because the process promote degradation of starch, loss of its granular structure and capacity to swell. Sprouted flour showed significantly lower viscosity values than others pearl millet flours ($p < 0.05$). The low viscosity of the sprouted flour was due to the lower proportion of starch molecules, which was hydrolyzed during plant metabolism. The peak viscosity of sprouted flour was only 48.2 cP **(Table 2)**. Obadina et al. (2016) reported that sprouted pearl millet flour for 48 h had a peak viscosity of 60 cP. Krishnan et al. (2011) observed that sprouted pearl millet flours significantly differed from raw and cooked flours.

Breakdown viscosity measures the paste stability, the higher breakdown value, the lower the material's ability to withstand heating and shear (JAMES *et al.,* 2018). In this research the raw and decorticated flours had higher breakdown values (245 to 343 cP) and differed significantly from all other processed flours ($p < 0.05$). The extrusion process (20.6 cP) did not promote significant difference ($p > 0.05$) in relation to the germination process (37.9 cP). Similar values were reported by (OBADINA *et al.*, 2016) which reported for sprouted pearl millet flour a breakdown of 42 cP.

The final viscosity defines the ability of the starch to form paste or gel after cooling (James et al., 2018). Decorticated flour obtained higher value (1860 cP) in the sequence of raw flour (1502 cP), extruded flour (149 cP), OH flour (199.2 cP), open pan boiling flour (212 cP) and germinated flour (38 cP). The final low viscosity of the sprouted flours indicated that this may be a good option for addition in products that wish to improve nutritional quality, but not to improve the viscosity of the product. However, the use of the decorticated flour is a better alternative for the preparation of thicker crumbs and products that wish to increase the viscosity after cooking.

Setback viscosity shows the tendency of retrogradation, due to a rapprochement of the amylose molecules and formation of intermolecular hydrogen bonds. The raw and decorticated flours showed a tendency to retrograde (set back from 1243 to 1620 cP), not being suitable for the development of refrigerated or frozen products, due to the occurrence of syneresis and change of appearance. Kharat *et al.* (2018) reported for pearl millet flour a setback of 2913 cP, higher than that reported in this research. Extruded flours obtained set back of 87 cP. Patil *et al.* (2016) reported set back of 132 cp for extruded finger millet flours. Segundo Patil et al. (2016) although it has lower viscosity than raw flour, the extruded pearl millet flour can be successfully used for the production of functional breads, promoting greater softness, cohesiveness and resilience. The sprouted flours obtained the lowest value of setback (27 cP). Obadina *et al.* (2016) reported for sprouted pearl millet flour similar values of setback (16.1 cP). However, James *et al*. (2018) reported values much lower ~ 1.5 cP. The low setback value of the sprouted flours may have useful application, for example, for use in the production of frozen breads that undergo freeze-thaw cycles, increasing the nutritional value of this product, without promoting greater modifications.

4 CONCLUSION

The results indicated that the physical, biological and thermal processes applied in pearl millet grains, significantly influenced the chemical and functional properties of the flours. The decortication, as predicted, was the processing that most impacted in the reduction of the content of nutrients. Decorticated flour had a reduction of 5% of proteins, 67% of lipids, 41% of fiber and 31% of calcium content, when compared to non decorticated flour. However, the decortication process associated with milling may have promoted industrial advantages such as flours with higher paste viscosity and lower lipid content that may have helped to increase shelf life. Germination did not promote nutrient reduction or increase. Besides, germination process promoted increased IAA, ISA, reduced overall paste viscosity including retrogradation viscosity, which may be, a viable alternative to be used as ingredient in vegetable beverage and frozen food formulations. The flours obtained for cooking by both methods (CONV. or OH) showed very similar nutritional and functional, except for mineral content that ohmic heating promoted significant reduction. Thermoplastic extrusion proved to be a technology that besides promoting an increased of flour solubility, water absorption also proved to be capable of maintaining the nutrients.

Future investigations are needed to evaluate the nutrient bioavailability and protein digestibility of flour. In addition, the assessment of the lipid stability of flours during storage and a study on the product acceptance should be evaluated before the flours are marketed. Also, studies on the impacts of processing on phenolic compounds and use of different flours in the production of various products should be explored.

Furthermore, investigations about the possible presence of mycotoxins and heavy metals in pearl millet grains commercialized in Brazil should be also investigate for industrial food use applications. Thus, the present work showed that processed pearl millet obtained by various processes can be nutritious and are a useful the versatile option for development of gluten free products.

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5 REFERENCES

ADEBIYI, J.A., OBADINA, A.O., MULABA-BAFUBIANDI, A.F., ADEBO, O.A., KAYITESI, E., 2016. Effect of fermentation and malting on the microstructure and selected physicochemical properties of pearl millet (*Pennisetum glaucum*) flour and biscuit. **Journal of Cereal Science** 70, 132-139, 2016.

AGTE, V.V.,. Effect of Traditional Food Processing on Phytate Degradation in Wheat and Millets. **J Agric Food Chem** 45, 1659-1661, 1997.

AKINOLA, S.A., BADEJO, A.A., OSUNDAHUNSI, O.F., EDEMA, M.O.,. Effect of preprocessing techniques on pearl millet flour and changes in technological properties. **International Journal of Food Science & Technology** 52, 992-999, 2017.

ANDERSON, R., CONWAY, H., PEPLINSKI, A.,. Gelatinization of corn grits by roll cooking, extrusion cooking and steaming. **Starch-Stärke** 22, 130-135, 1970.

AGÊNCIA NACIONAL DE VIGILÂNCIA SANITÁRIA (ANVISA). Resolução RDC nº 54, de 12 de novembro de 2012. Dispõe sobre regulamento técnico sobre informação nutricional complementar. **Diário Oficial da República do Brasil,** Brasília, 13 nov. 2012.

AGÊNCIA NACIONAL DE VIGILÂNCIA SANITÁRIA (ANVISA). Resolução de Diretoria Colegiada. RDC nº 359, de 23 de dezembro de 2003. **Aprova Regulamento Técnicode Porções de Alimentos Embalados para Fins de RotulagemNutriciona**l. Diário Oficial da União; Poder Executivo, de 26 de dezembrode 2003. 2003a.

AGÊNCIA NACIONAL DE VIGILÂNCIA SANITÁRIA (ANVISA). Resolução de Diretoria Colegiada RDC nº 360, de 23 de dezembro de 2003. **Aprova Regulamento Técnico sobre Rotulagem Nutricional de Alimentos Embalados**, tornando obrigatória a rotulagem nutricional. Diário Oficial da União; Poder Executivo, de 26 de dezembro de 2003. 2003b.

ARES, G., VIDAL, L., ALLEGUE, G., GIMÉNEZ, A., BANDEIRA, E., MORATORIO, X., MOLINA, V., CURUTCHET, M.R.,. Consumers' conceptualization of ultra-processed foods. **Appetite** 105, 611-617, 2016.

BORA, P., RAGAEE, S., MARCONE, M.,. Effect of parboiling on decortication yield of millet grains and phenolic acids and in vitro digestibility of selected millet products. **Food Chemistr**y 274, 718-725, 2019.

CHANDRA, S., SINGH, S., KUMARI, D.,. Evaluation of functional properties of composite flours and sensorial attributes of composite flour biscuits. **Journal of Food Science and Technology** 52, 3681-3688, 2015.

CODEX ALIMENTARIUS COMMISSION, J.F.W.C.A., Organization, W.H., Programme, J.F.W.F.S., 2007. Cereals, Pulses, Legumes and Vegetable Proteins. **Food & Agriculture Org. CODEX Standard 170-1989**.Standard for pearl millet flours, 2007.

COULIBALY, A., KOUAKOU, B., CHEN, J.,. Extruded adult breakfast based on millet and soybean: Nutritional and functional qualities, source of low glycemic food. **Nutrition & Food Sciences,** 2012.

DEVISETTI, R., YADAHALLY, S.N., BHATTACHARYA, S.,. Nutrients and antinutrients in foxtail and proso millet milled fractions: Evaluation of their flour functionality. **LWT - Food Science and Technology** 59, 889-895, 2014.

DIAS-MARTINS, A. M., CAPPATO, L. P., DA COSTA MATTOS, M., RODRIGUES, F. N., PACHECO, S., & CARVALHO, C. W.. Impacts of ohmic heating on decorticated and whole pearl millet grains compared to open-pan cooking. **Journal of Cereal Science**, 85, 120-129, 2019.

DIAS-MARTINS, A.M., PESSANHA, K.L.F., PACHECO, S., RODRIGUES, J.A.S., CARVALHO, C.W.P.,. Potential use of pearl millet (*Pennisetum glaucum* (L.) R. Br.) in Brazil: Food security, processing, health benefits and nutritional products. **Food Research International** 109, 175-186, 2018.

DU, S.-K., JIANG, H., YU, X., JANE, J.-L., Physicochemical and functional properties of whole legume flour. **LWT - Food Science and Technology** 55, 308-313, 2014.

EUROMONITOR INTERNATIONAL, 2018 .https://www.euromonitor.com/health-and-wellness-in-brazil/report

FAROOQ, A.M., LI, C., CHEN, S., FU, X., ZHANG, B., HUANG, Q.,. Particle size affects structural and in vitro digestion properties of cooked rice flours**. International Journal of Biological Macromolecules** 118, 160-167, 2018.

FDA. **Labeling Nutrition**. https://www.fda.gov/Food/LabelingNutrition/ucm20026097.htm

GONG, K., CHEN, L., LI, X., SUN, L., LIU, K.,. Effects of germination combined with extrusion on the nutritional composition, functional properties and polyphenol profile and related in vitro hypoglycemic effect of whole grain corn. **Journal of Cereal Science** 83, 1-8, 2018.

GULATI, P., WEIER, S.A., SANTRA, D., SUBBIAH, J., ROSE, D.J.,. Effects of feed moisture and extruder screw speed and temperature on physical characteristics and antioxidant activity of extruded proso millet (*P anicum miliaceum*) flour. **International Journal of Food Science & Technolog**y 51, 114-122, 2016.

GULL, A., PRASAD, K., KUMAR, P.,. Evaluation of functional, antinutritional, pasting and microstructural properties of Millet flours. **Journal of Food Measurement and Characterization** 10, 96-102, 2016.

HAMA, F., ICARD-VERNIÈRE, C., GUYOT, J.-P., PICQ, C., DIAWARA, B., MOUQUET-RIVIER, C.,. Changes in micro-and macronutrient composition of pearl millet and white sorghum during in field versus laboratory decortication. **Journal of Cereal Science** 54, 425-433, 2011.

HIDALGO, A., FONGARO, L., BRANDOLINI, A.,. Wheat flour granulometry determines colour perception. **Food Research International** 64, 363-370, 2014.

ITAL. Institute of Food Technology, 2016. **Alimentos processados**. http://www.alimentosprocessados.com.br/′. Accessed 14.09.18, 2016.

JAFARI, M., KOOCHEKI, A., MILANI, E.,. Effect of extrusion cooking on chemical structure, morphology, crystallinity and thermal properties of sorghum flour extrudates. **Journal of Cereal Science** 75, 324-331, 2017.

JAMES, S., AKOSU, N.I., MAINA, Y.C., BABA, A.I., NWOKOCHA, L., AMUGA, S.J., AUDU, Y., OMEIZA, M.Y.M.,. Effect of addition of processed bambara nut on the functional and sensory acceptability of millet-based infant formula. **Food science & nutrition** 6, 783-790, 2018.

JHA, N., KRISHNAN, R., MEERA, M.S.,. Effect of different soaking conditions on inhibitory factors and bioaccessibility of iron and zinc in pearl millet. **Journal of Cereal Science** 66, 46-52, 2015.

KERR, W.L., WARD, C.D.W., MCWATTERS, K.H., RESURRECCION, A.V.A.,. Milling and particle size of cowpea flour and snack chip quality. **Food Research International** 34, 39-45, 2001.

KHARAT, S., MEDINA-MEZA, I.G., KOWALSKI, R.J., HOSAMANI, A., C.T, R., HIREGOUDAR, S., GANJYAL, G.M.,. Extrusion processing characteristics of whole grain flours of select major millets (Foxtail, Finger, and Pearl). **Food and Bioproducts Processing**, 2018.

KRAITHONG, S., LEE, S., RAWDKUEN, S.,. Physicochemical and functional properties of Thai organic rice flour. **Journal of Cereal Science** 79, 259-266, 2018.

KRISHNAN, R., DHARMARAJ, U., MANOHAR, R.S., MALLESHI, N.,. Quality characteristics of biscuits prepared from finger millet seed coat based composite flour. **Food Chemistry** 129, 499-506, 2011.

NAQASH, F., GANI, A., GANI, A., MASOODI, F.A., . Gluten-free baking: Combating the challenges - A review. **Trends in Food Science & Technolog**y 66, 98-107, 2017.

NKAMA, I., GBENYI, D., HAMAKER, B., . Effects of malting and roasting of millet and sorghum on protein digestibility, mineral availability, soluble sugar composition and consumer acceptability of Dakuwa. **Indian Journal of Nu**trition 2, 1-6, 2015.

N'Dri, D., Mazzeo, T., Zaupa, M., Ferracane, R., Fogliano, V., Pellegrini, N., 2013. Effect of cooking on the total antioxidant capacity and phenolic profile of some whole-meal African cereals. **Journal of the Science of Food and Agriculture** 93, 29-36, 2013.

OBADINA, A., ISHOLA, I.O., ADEKOYA, I.O., SOARES, A.G., DE CARVALHO, C.W.P., BARBOZA, H.T., . Nutritional and physico-chemical properties of flour from native and roasted whole grain pearl millet (P*ennisetum glaucum* [L.]R. Br.). **Journal of Cereal Science** 70, 247-252, 2016.

OMOBA, O.S., TAYLOR, J.R., DE KOCK, H.L.,. Sensory and nutritive profiles of biscuits from whole grain sorghum and pearl millet plus soya flour with and without sourdough fermentation. **International Journal of Food Science & Technology** 50, 2554-2561, 2015.

OSHODI, H.O., MO OLADIMEJI, AA,. Chemical composition, nutritionally valuable minerals and functional properties of benniseed (*Sesamum radiatum*), pearl millet (*Pennisetum typhoides*) and quinoa (*Chenopodium quinoa*) flours. **Int J Food Sci Nutr** 50, 325-331, 1999.

PATEL, S.,. Functional food relevance of whey protein: A review of recent findings and scopes ahead. **Journal of Functional Foods** 19, Part A, 308-319, 2015.

PATIL, S.S., RUDRA, S.G., VARGHESE, E., KAUR, C.,. Effect of extruded finger millet (Eleusine coracan L.) on textural properties and sensory acceptability of composite bread. **Food Bioscience** 14, 62-69, 2016.

PUSHPARAJ, F.S., UROOJ, A.,. Influence of processing on dietary fiber, tannin and in vitro protein digestibility of pearl millet. **Food and Nutrition Sciences** 2, 895-900, 2011.

Rai, S., Kaur, A., Singh, B., 2014. Quality characteristics of gluten free cookies prepared from different flour combinations. **Journal of Food Science and Technology** 51, 785-789, 2014.

SHARMA, N., GOYAL, S., ALAM, T., FATMA, S., NIRANJAN, K.,. Effect of Germination on the Functional and Moisture Sorption Properties of High–Pressure-Processed Foxtail Millet Grain Flour. **Food and bioprocess technology** 11, 209-222, 2018.

SUMATHI, A., USHAKUMARI, S., MALLESHI, N., . Physico-chemical characteristics, nutritional quality and shelf-life of pearl millet based extrusion cooked supplementary foods. **Int J Food Sci Nutr** 58, 350-362, 2007.

THILAGAVATHI, T., KANCHANA, S., BANUMATHI, P., HEMALATHA, G., VANNIARAJAN, C., SUNDAR, M., ILAMARAN, M.,. Physico-chemical and functional characteristics of selected millets and pulses. **Indian Journal of Science and Technology** 8, 147-155, 2015.

TAYLOR, J.R.N.,. Millet Pearl: Overview, Encyclopedia of Food Grains (Second Edition). Academic Press, Oxford, pp. 190-198, 2016.

TIWARI, A., JHA, S., PAL, R., SETHI, S., KRISHAN, L.,. Effect of Pre-Milling Treatments on Storage Stability of Pearl Millet Flour. **Journal of Food Processing and Preservation** 38, 1215-1223, 2014.

VARGAS-SOLÓRZANO, J.W., CARVALHO, C.W.P., TAKEITI, C.Y., ASCHERI, J.L.R., QUEIROZ, V.A.V.,. Physicochemical properties of expanded extrudates from colored sorghum genotypes. **Food Research Intern**ational 55, 37-44, 2014.

ZAREIFARD, M. REZA et al. Factors influencing electrical conductivity. Ohmic heating in food processing, p. 53, 2014.

CONCLUSÃO GERAL

Neste trabalho concluiu-se que grãos de *Pennisetum glaucum* L. R. Br tem grande potencial nutricional e tecnológico para serem utilizados como uma nova alternativa alimentar dos brasileiros. A cultura tem grande relevância para segurança alimentar para o país pois possui características agronômicas diferenciadas como alta resistência a mudanças climáticas, elevada tolerância a seca, a baixa fertilidade de solo e a alta salinidade de solo. Características que devem ser utilizadas para encorajar a plantação desta cultura na região semiárida do Nordeste brasileiro, pois ajudaria a expandir as opções de alimentos nutritivos para os animais e agricultores. Os grãos apresentaram diâmetro médio de 2,0 mm e características nutricionais superiores a cereais como milho, arroz e sorgo. Segundo as legislações vigentes RDC 54/12 e RDC 360/03 da ANVISA, grãos de milheto podem ser classificados como fontes de proteínas e fibras alimentares. Além disso, não são transgênicos, são isentos de glúten e possuem valor de custo inferior a cereais como milho e arroz.

Os resultados nos levaram a concluir que grãos de milheto integrais e decorticados podem ser consumidos cozidos de forma similar ao arroz, em panela aberta com água fervente ou por aquecimento ôhmico à 98ºC por 30min e 20 min, respectivamente. A tecnologia de aquecimento ôhmico mostrou-se ser promissora para cozinhar grãos de milheto, já que não causou nenhum efeito negativo nos atributos nutricionais e funcionais dos grãos e por ser uma tecnologia que possui alta eficiência energética. Além disso, os resultados dos demais processos mostraram que os grãos podem ser consumidos germinados em forma de brotos, extrusadas em forma de snacks ou cereais matinais ou também como farinhas.

Em relação as farinhas, aquelas obtidas por decorticação (10 min) apresentaram reduzido valor nutricional, quando comparada com a farinha integral. Porém, farinhas decorticadas seguidas das farinhas integrais apresentaram os maiores valores de viscosidade. Isto indica que, podem ser utilizados como ingredientes para preparação de minguas e vitaminas, por exemplos. As farinhas extrusadas possuem vantagens tecnológicas, devido ao maior valor de solubilidade e absorção de água apresentados, mostrando que podem ser indicadas para enriquecer formulações de bebidas, sopas ou produtos instantâneos, prontos para consumo. As farinhas germinadas apresentaram a mesma composição nutricional que a farinha integral crua, não tendo sido observado melhorias nutricionais no cultivar analisado. Quanto aos aspectos tecnológicos, a farinha germinada apresentou menor solubilidade apenas da farinha extrusada. Este ingrediente apresentou baixa tendência a retrogradação e, por isso, pode ser uma opção útil para enriquecer nutricionalmente alimentos congelados com pães, por exemplo.

Apoio às instituições de pesquisas são necessários para continuar os estudos sobre o os potenciais usos desta cultura na alimentação brasileira. Devem ser realizados estudos que avaliem os efeitos de diferentes processamentos no teor de aminoácidos, na digestibilidade proteica, no teor de compostos fenólicos, na inibição de enzimas α e β amilase e na atividade antioxidante. Estudos que avaliem o efeito de processamentos na redução dos fatores antinutricionais. Estudos que investiguem a estabilidade lipídica de farinhas integrais cruas e processadas e também, identifiquem novos parâmetros de processo para desenvolvimento de snacks e cereais matinais. Avaliações sensoriais de variados produtos devem ser incentivados além de estudos sobre intensão de compra destes produtos. Efeitos de outros tratamentos emergentes como alta pressão e ozonização devem ser explorados. Avaliações quanto a presença de micotoxinas e metais pesados nos grãos de milheto deve ser investigados. Além disso, a realização de ensaios clínicos precisam ser explorados a fim de melhor elucidar os efeitos hipoglicêmicos e goitrogênicos já relatados deste cereal na literatura.

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