Characteristics changes of Pasuruan locally grown brown sorghum grain due to extrusion process

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Abstract. Commercial extruded snacks available in the Indonesian market are generally cereal-based, such as from corn and rice, and there is not any that is from brown sorghum. This research aims to study changes in physical and chemical characteristics of brown sorghum grains after extrusion and compare the extrudate characteristics of products from brown sorghum grains, corn, and rice. Brown sorghum grains are de-husked, ground into grits, and extruded using a single screw extruder at 120°C. The resulting extrudates are then analyzed and compared to rice and corn extrudates. There is a change in chemical content after the sorghum grains are extruded. The content of moisture, fat, starch, and protein decreased, while the content of reducing sugar, ash, and fiber increased. The content of anti-nutritional compounds such as tannins, phytates, kafirin, and disulfide bonds decreased; so that the digestibility value increased from 48.44% (grains) to 75.67% (extrudates). Compared with extrudates from rice and corn, sorghum seed extrudate has the smallest expansion ratio, higher density, darker color, but still has a similar quality in texture.

1. Introduction
Sorghum is one type of cereal that has better adaptability to drought than other cereal crops [1], such as corn and rice. One type of sorghum that can be grown and cultivated during the dry season is local brown sorghum. Brown sorghum grains have a colored test layer (brown) with high tannin content [2]. High tannin content correlates with the poor taste of sorghum [3] and its low level of digestibility. Thus, limiting the use of brown sorghum grains as food sources. However, the natural presence of tannins and other phenolic compounds in sorghum has been extensively used by humans as a functional food to support health benefits [4].

So far, the use of local brown sorghum has been limited to traditional food ingredients or rice substitutes. Therefore, there is a need to expand its usages, one of them is through extrusion technology. Extruded starch has higher thermal stability, lower cold paste viscosity, and softer gel; so that it can be used as one of the ingredients in the manufacturing of food products, such as bread, cakes, and puddings [5]. Sorghum extrudate can be used as an ingredient in desserts that have a low glycemic index (GI), which can be used as food for people with diabetes [5].

Extrusion is a mechanical process that exposes ingredients at a high temperature, shear and pressure rapidly [6]. Extrusion technology is used by the food industry to produce expanded snacks due to several advantages, which are low cost, flexibility, continuous process, and versatility [7]. Almost all existing studies state that starch is the main polymer that is important in the expansion of extrudate products. Maximum expansion (500%) can be reached if the ingredient is pure starch [8], and the lowest level of
starch content permitted to allow extrudate products to expand well is between 60-70% [8]. For that reason, it is not surprising that extrudate snacks are generally made from cereals with high levels of starch, such as corn and rice. Brown sorghum grains also have a high level of starch, which is 79.40% [9], thus they fulfill the criteria to have good expansion when processed with extrusion technology.

The particle of grains needs to be reduced being grits before extrusion. Extrudates from smaller grain particles have higher starch digestibility than larger grain particles [10]. In the process of extrusion, generally, the moisture content of ingredients is adjusted by increasing the water content to support starch gelatinization and extrudate expansion. If the grains still contain a seed coat, the water penetration will be slower; if the grit is coarse, then the ratio of surface to volume is lower than that of smaller particles so that the absorption of water by the particles is also slower [10]. Corn-based extrudate produces snacks with excellent texture, but from the nutritional point of view, there are some weaknesses, which are low protein and fiber contents [7]. Unpolished local brown sorghum contains protein (11.78%) and fiber (4.12%), which are quite high [9]. However, the presence of proteins with many disulfide bonds, fibers, and other components in sorghum grains, such as tannin, may affect the expansion and physical and chemical characteristics of the resulting extrudates. Therefore, this study was conducted to evaluate changes in the characteristics of sorghum grains after going through the extrusion process, and also to compare the characteristics of sorghum extrudates with extrudates from corn and rice, which are more commonly used as one of the ingredients in snacks and other products from the extrusion process.

2. Materials and methods
The main material used in this research is brown sorghum grains of local variety from Rejoso village, Grati Subdistrict, Pasuruan Regency, East Java Province. The comparison ingredients are white rice (Mentari) and commercial corn grit obtained from the Kebalen market, Malang. Sorghum grains were de-husked, ground into grits, and extruded using a single screw extruder (type MX-3001) at 120°C. The sorghum extrudate was then compared for its physical and chemical characteristics with those of corn and rice produced using the same machine and extrusion conditions.

Analyses were carried out to compare changes in the chemical characteristics of sorghum grains and sorghum extrudate. The analyses included the moisture content by using the gravimetric method, the protein content by using the macro-Kjeldahl method, the reducing sugar by using the Nelson-Somogyi method, the fiber content, the ash content, the starch content by using the direct acid hydrolysis method [11], total phenol, tannin, acid phytate, antitrypsin [12], disulfide bonding, and protein digestibility by using the pepsin-trypsin enzyme [9].

Analyses were also carried out to compare the physical and chemical characteristics of sorghum, corn, and rice extrudates. The analyses included the expansion ratio measured by dividing the diameter of the extrudates by the diameter of the die (13), the density by comparing the weight divided by the volume of the extrudate (14), the texture and color in the Lab (15), the moisture content, ash, fiber, fat and starch (11).

This research is descriptive. Data were taken from 3 replications. Data will be presented in means±sd (standard deviation). The comparison between the characteristics of sorghum grains and the characteristics of sorghum extrudate was conducted by using the T-test, while the comparison between the characteristics of sorghum, corn, and rice extrudates was conducted by one-way ANOVA and LSD test of α=5%.

3. Results and discussion
3.1. The comparison between the chemical characteristics of sorghum grains and sorghum extrudates
Various characteristics of polished brown sorghum grains and sorghum extrudate are presented in Table 1. The extrusion process affected reducing moisture content, protein, and antinutrient compounds, such as tannin, phytic acid, and disulfide bonds. The extrusion process also affected the increase in fiber
content, reducing sugar content, and digestibility. However, the content of ash, fat, starch, total phenol, and antitrypsin did not change much by the extrusion process.

**Table 1.** Chemical characteristics of polished brown sorghum grain and the extrudate.

| Characteristic       | Grain (±SD)  | Extrudate (±SD) | P-value |
|----------------------|--------------|-----------------|---------|
| Moisture (%)         | 9.39±0.72    | 6.74±0.55       | 0.002*  |
| Ash (%)              | 0.43±0.10    | 0.47±0.08       | 0.718   |
| Fiber (%)            | 0.41±0.06    | 1.35±0.09       | 0.001*  |
| Fat (%)              | 0.74±0.06    | 0.54±0.05       | 0.068   |
| Starch (%)           | 78.18±1.81   | 74.37±1.77      | 0.149   |
| Reducing sugar (%)   | 0.03±0.01    | 7.29±0.07       | 0.000*  |
| Protein (%)          | 10.26±0.58   | 6.77±0.9        | 0.006*  |
| Total phenol (mg/g)  | 11.41±0.14   | 11.61±0.16      | 0.085   |
| Tannin (mg/g)        | 8.82±0.04    | 4.59±0.25       | 0.001*  |
| Phytic acid (mg/g)   | 2.08±0.12    | 1.15±0.04       | 0.013*  |
| Antitrypsin (mg/g)   | 16.74±1.62   | 15.23±1.00      | 0.419   |
| S-S bond (mg/g)      | 42.77±1.07   | 25.04±4.17      | 0.011*  |
| Digestibility (%)    | 48.98±0.43   | 75.67±2.01      | 0.001*  |

Note: Data are means of 3 replications (± standard deviation). * It means a significant different

The moisture content of sorghum grains decreased after extrusion. This decrease in moisture content occurred due to the use of hot temperature (120°C) that changed water from liquid to steam, which is easily evaporated. Water plays a role in hydrating starch and making starch plastic, and turning it into a rubbery state, when the extrusion temperature is higher, a viscoelastic melt is formed. When the melting exits the extruder die, water flashes off and makes the extrudate expands [8].

Ash content indicates the presence of minerals in the ingredients. The ash content during the extrusion process did not change. Mineral components are resistant to high temperature and pressure, as well as mechanical forces in the extrusion process. However, the extrusion process can increase the dialyzability and bio-availability of several minerals important to the human body, such as Mg, P, K, and Fe, as a result of the decrease in the phytate content that binds these minerals [16].

Fiber increased when sorghum grains were extruded. One of the reasons for this increase in fiber is the formation of resistant starch through the starch retrogradation process. When the extrudate had been cooled down and stored, there was an increase in starch retrogradation [5].

Statistically, the content of fat and starch of polished sorghum grains and the extrudate are the same. However, there is a tendency to decrease. The high temperature and screw speed during the extrusion process can cause fat degradation [17]. Fat may also interact with starch components and forms new structures. The decrease in starch content was accompanied by an increase in reducing sugar content. This is because, during the extrusion process, starch degradation occurs due to heat, high pressure, and mechanical treatment into compounds with lower molecular weights [17].

Protein content decreased after extrusion. Temperature and high pressure in the extrusion process are able to cause the breaking of inter and intramolecular bonds, however, the split protein units still have peptide bonds, which are analyzed as total N, so it will not change the protein amount. However, the extrusion process also allows interactions between components, so that new structures cannot be analyzed as proteins are formed.

Apart from tannin, there are other non-tannin components, such as phenolic acid and flavonoid, that determine total phenolic content. The amount of total phenolic content did not change significantly, but the amount of tannin decreased significantly after sorghum grains were extruded. The decrease in the amount of tannin was possibly due to tannin undergoing decarboxylation due to the influence of high temperature and the presence of moisture, then it formed polymerization of phenols and tannins, thus reducing its extractability [18]. The decrease in the amount of tannin has a good effect on protein
digestibility. Tannin can bind to protein [19] so that a decrease in the amount of tannin will increase the accessibility of protease enzymes to their substrates.

The extrusion also reduced the amount of phytic acid and disulfide bonds, although it did not significantly reduce the amount of antitrypsin. The decrease of antinutrient contents caused by extrusion has been previously reported. In lentils, extrusion can reduce phytic acid by 99%, trypsin inhibitor by 99%, and tannin by 98% [12]. Phytic acid, tannin, and trypsin inhibitors can interact and form a complex compound with protein, making them less susceptible for proteolytic to hydrolyze. The decrease of disulfide compounds made the protein structure more easily hydrolyzed by proteases [12]. So that the decrease in antinutrients had a positive effect on increasing the digestibility of sorghum extrudate protein. Increased digestibility when sorghum grains are extruded can also be caused by high temperatures which can produce gelatinized starch and denatured protein. The main effect of the extrusion process is to open the endosperm structure of the seed, thereby shortening the meeting path of the enzyme and its substrate [10].

3.2. Characteristic differences of sorghum extrudate and corn and rice extrudate

There was not a significant difference in moisture content between the extrudates of sorghum, corn, and rice. From the nutritional point of view, sorghum extrudate; fiber, starch, and protein were generally comparable to corn and rice extrudates. Sorghum extrudate has the advantage that it is higher in protein content, but in terms of starch and fiber, rice extrudate has the highest numbers, in comparison to sorghum and corn.

| Characteristic | Sorghum | Corn | Rice |
|---------------|---------|------|------|
| Moisture (%)  | 6.74±0.55 a | 7.18±0.31 a | 6.90±0.20 a |
| Fiber (%)     | 1.35±0.09 b | 1.22±0.02 b | 1.70±0.20 a |
| Starch (%)    | 74.37±1.77 b | 76.03±1.36 b | 80.22±0.34 a |
| Protein (%)   | 6.77±0.90 a | 6.09±0.23 b | 3.36±0.23 a |
| Expansion ratio | 101.67±7.64 c | 153.33±5.77 a | 126.67±2.89 b |
| Density (g/L) | 40.49±0.48 a | 29.43±1.17 b | 35.13±1.78 b |
| Texture (mm/g.s) | 0.07±0.01 a | 0.10±0.01 a | 0.10±0.04 a |
| Color L       | 52.16±2.25 b | 66.57±2.30 a | 64.45±2.74 a |
| Color a       | 13.04±1.82 b | 17.77±3.17 b | 23.12±2.70 a |
| Color b       | 16.5±0.53 c  | 31.30±1.22 a | 22.76±1.69 b |

Note: Data are means of 3 replications (± standard deviation). The same symbol in the same row shows the insignificant difference on Tukey’s HSD test α=0.05

The expansion ratio of sorghum extrudate is the lowest in comparison to corn extrudate and rice extrudate. This can be due to the composition of starch and protein. From Table 2, it can be seen that sorghum starch content is the lowest among corn and rice. Product development extrudate depends on many factors, both from material parameters such as material composition, molecular structure, and interactions between components, as well as operational parameters such as temperature, screw speed, and mechanical energy input [8]. Starch gelatinization is a key determining factor in the extrusion process; the higher the degree of gelatinization, the higher the expansion level of the extrudate [7]. The protein content of sorghum that is higher than corn and rice is also the cause of its low ratio of extrudate expansion. Protein can bind to starch, protein can also bind to water; thus, water that hydrates starch for the gelatinization process decreases, thereby reducing the starch expansion. In addition, the sorghum protein that is dominated by kafirin with many disulfide bonds makes a strong bond and strengthens the protein structure. The addition of fiber and protein increases the specific mechanical energy input, bulk density, and density of the air cell. If the contents of protein and fiber are high, the expansion is minimal [14].
The density of sorghum extrudate is the highest in comparison to corn and rice extrudates. Density generally correlates with the expansion ratio. If the expansion ratio is high, then the density value is low, and vice versa [13]. The texture of sorghum extrudate is statistically the same in comparison to corn and rice, but there is a tendency that the sorghum extrudate is harder than extrudates from corn and rice. Texture can be affected by starch composition. The hardness of sorghum extrudate may be caused by the higher amylose content (23.7% in sorghum and 18% in corn), which further causes starch retrogradation [5] when the extrudate has been cooled down/ stored.

The color of sorghum extrudate is the darkest in comparison to corn and rice extrudates. The color of the extrudate product can be influenced by the natural pigments present in the ingredient and the color formed during the process, one of which is the Maillard reaction [7]. The sorghum used in this study was brown sorghum, which has a pigment in form of tannins (Table 1), while corn grits are yellow due to carotenoids and rice is white, and these pigments also determine the color of the extrudates, which are brown, yellow and white respectively. The Maillard reaction is a reaction between reducing sugar and protein amino acids that happens at a high temperature for a certain time. When compared to corn and rice, sorghum has a higher protein content, so the Maillard reaction is more likely to occur.

4. Conclusions
Local varieties of sorghum grains can be processed through extrusion technology. The extrusion process changes several characteristics of local varieties of brown sorghum grains, such as the increase in protein digestibility, the decrease of antinutritional factors, and the decrease of moisture content. Sorghum extrudate has nutritional characteristics (starch, fiber, and protein), which is comparable to corn and rice extrudates. However, physically, sorghum extrudate has a smaller expansion ratio and higher density, thus further research is needed to (for instance) find optimum extrusion conditions and analyze the combination of brown sorghum grains with other ingredients that have a better expansion ratio. Sorghum extrudate also has a darker color than corn and rice, however, this unique natural brown color of sorghum extrudate can actually be an advantage, as it does not require the addition of a coloring additive.

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