MICROWAVE POPPING CHARACTERISTICS, CHEMICAL COMPOSITION AND MICROSTRUCTURE OF SORGHUM GRAIN
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ТЕХНОЛОГІЧНІ ЯКОСТІ, ХІМІЧНИЙ СКЛАД І МІКРОСТРУКТУРА ЗЕРНА СОРГО ДЛЯ МІКРОХВИЛЬОВОГО ПОПІНГУ

Svitlana MYKOLENKO[1),2)]*, Dmytro TYMCHAK[1)], Yuriy TCHOURSINOV[1)], Mykola KHARYTONOV[1),2)]
[1)]Dnipro State Agrarian and Economic University, S. Yefremova Str. 25, 49600 Dnipro, Ukraine
[2)]BETA Tech Center, University of Vic, de Roda st. 70, 08500 Vic, Spain
Tel: +380989642684; E-mail: svetlana.mykolenko@gmail.com
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ABSTRACT
The chemical composition, physical properties (moisture, crude protein, crude fiber, ash content, thousand grain weight, bulk density) and grain microstructure were evaluated for different varieties of sorghum grain cultivated in Ukraine. Sorghum varieties (Dniprovsky, Kafrske, and Fulgus) were subjected to different preconditioning and process parameters of microwave heating to determine the popping characteristics of the grain. Each of the three sorghum varieties was pretreated by moisture conditioning up to 13, 15, and 17%, and popped in a microwave oven set at 450, 600 and 700 W for 150 s. Popping yield was insufficient for all sorghum varieties at microwave power 450 W and grain moisture content of 13 and 17%. Popping characteristics (popping yield, popping start, specific weight of popped grain and volume expansion ratio) and organoleptic properties were measured. Thousand grain weight, bulk density, protein, ash, crude fiber content, pericarp, aleurone, and translucent endosperm thickness were found to be significantly different among the three sorghum varieties. Varietal characteristics of sorghum grain had a strong impact on volume expansion ratio, which was negatively correlated with the size of the grain. The Fulgus grain variety showing the highest popping characteristics was found to have higher thousand grain yield (31.9 g), higher bulk density (869.8 g/dm^3), lower protein (8.03%), ash (1.35%) and crude fiber (2.01%) content, thinner but well-packed pericarp (31 µm), thinner aleurone (9 µm) and thicker translucent endosperm (1.1 mm) than other varieties.

АНОТАЦІЯ
Оцінювали хімічний склад, фізичні якості (вологість, сирий протеїн, сиру клітковину, зольність, масу тисяч зерен, натурну масу) та мікроструктуру зерна для різних сортів зерна сорго, вирощених в Україні. Зерно різних сортів сорго (Дніпровський, Кафрське, Фулгус) піддавали різним режимам попереднього кондиціювання та параметрам мікрохвильової обробки задля визначення характеристик отримання повітряного зерна. Зерно кожного з трьох сортів сорго попередньо кондиціонували при вологості 13, 15, 17% і обробляли мікрохвильовим опроміненням при потужності генератора 450, 600 і 700 Вт протягом 150 с. Вихід поп-сорго був недостатнім для всіх сортів сорго при потужності мікрохвильової обробки 450 Вт і вологості зерна 13 і 17 %. Було визначеного характеристики отримання повітряного зерна (вихід поп-сорго, початок попінгу, питома маса поп-сорго, коефіцієнт об'ємного розширення) та органолептичні властивості. Було виявлено, що маса тисячі зерен, натурна маса, вміст білку, золи та сирої клітковини, товщина перикарпію, алейронового шару і напівпрозорого ендосперму значно відрізняються для досліджених сортів сорго. Сортові характеристики зерна сорго мали сильний вплив на коефіцієнт об'ємного розширення, що негативно корелювало із розміром зерна. Виявлено, що сорт зерна Фулгус, який демонстрував найвищі попінг-якості, характеризувався більшою масою тисячі зерен (31,9 г), більш високою натурною масою (869,8 г/дм^3), меншим вмістом білка (8,03%), золи (1,35%) і сирої клітковини (2,01%), більш тонким, але добре упакованим перикарпієм (31 мкм), більш тонким алейроновим шаром (9 мкм) і більшим вмістом напівпрозорого ендосперму (1,1 мм) порівняно з іншими сортами.

INTRODUCTION
Lately, there has been a growing interest in unconventional flours, including gluten-free ones, such as sorghum flour (*Cruickshank et al., 2016; Girard and Awika, 2018; Winger et al., 2014*). The acceleration of human life has triggered an increase in the number of foods that can quickly satisfy hunger (*Hess et al., 2016*).

Therefore, the increase in the production of snacks, which are mainly based on cereals, has reached 120–150% over the last decade (*Pries et al., 2019*). Physical methods of grain processing significantly affect its functional properties (*Kim et al., 2021; Oyeyinka et al., 2019*). Usually, the most popular methods for popping are convective and microwave treatment (*Li et al., 2021*). Convective treatment can lead to the accumulation of toxic compounds such as acrylamide, which is not only carcinogenic but also genotoxic (*Bocharova et al., 2012*). Microwave treatment as a method of popping has several advantages, consisting of uniform heating of the product, energy efficiency, more complete preservation of nutrients and destruction of harmful microbiota (*Barba et al., 2020; Los et al., 2018*). During microwave treatment, heating occurs due to the molecular friction of the electric dipoles and charged molecules under an oscillating field of a specific frequency (*Ibrahim et al., 2012; Sun et al., 2016*). During this process, the heated steam obtained inside the grain by instant heating suddenly widens the endosperm, tearing the outer layers. The main popping characteristics of grains are popping yield, specific weight of popped grains and volume expansion ratio (*Mishra et al., 2014; Srdic et al., 2015*). Researchers reported that the size of the grain, endosperm structure, and pericarp thickness affected the popping quality of grains significantly (*Mishra et al., 2015*). The efficiency of the popping of sorghum grains is known to be significantly dependent on both the varietal characteristics of the grain (*Mykolenko and Tymchak, 2019; Rooney and Rooney, 2013*) and technological factors of the processing. For example, the popping characteristics of the grain depending on the variation of such technological factors as moisture content of the grain and microwave power during heating (*Tymchak et al., 2018*). According to the research of Ukrainian breeding research institutions, more than 300 varieties of sorghum were developed including *Sorghum bicolor*, *Sorghum saccuratum*, and *Sorghum sudanense* species (*Karazhbey, 2012*). Despite the changing climatic conditions in Ukraine and related reducing the production of traditional crops (*Bykin et al., 2019*), there is practically no research on the popping characteristics of Sorghum bicolor varieties cultivated in Ukraine as well as in Europe at all. This creates obstacles to supply the popping industry with products of decent popping characteristics for the production of snacks, including popped sorghum grains, in Ukraine and beyond.

This work aims to study the grain microstructure and chemical composition of Sorghum bicolor varieties cultivated in Ukraine, and finding the effective pretreatment and microwave processing parameters affecting the popping characteristics.

MATERIALS AND METHODS

Varieties of sorghum grain, Dniprovsky, Fulgus, Kafrske were cultivated at Synelnykove Crop Breeding Experimental Station, Institute of Grain Crops of the National Academy of Agrarian Sciences of Ukraine, Ukraine, and harvested in 2018. A sample of 5 kg was procured for the investigation, cleaned, graded and stored at 18–24°C for six months. Thousand grain weight of the sorghum grain samples of the three varieties were determined by weighing 1000 grains (*Simonyan et al., 2007*). Bulk density was measured as the weight of sample per unit volume by the standard method (ISO 7971-2:2019). The gravimetric method was adopted to determine the moisture content of different grain samples. A sample of 5 g was kept in a hot air oven at 105 ºC for 24 h. The mean of three replications was calculated and used for analysis. Protein content (CF=6.25) was determined by the Kjeldahl method using equipment Kjel Flex K-360 (BUCHI, Germany). For ash content determination, grinded sorghum grains in the crucibles were ashed at 525 ºC for 6 h in a muffle furnace (Nabertherm, Germany). The crude fiber was determined by the method based on removing compounds solving in acids, and alkalis and determining the weight of the undissolved residue as crude fiber (*Roik and Kuznetsova, 2017*) using equipment FIWE 3 (Velp Scientifica, Italy). Moisture conditioning was performed to bring the moisture content of sorghum grain to 13, 15, and 17% levels for determination of the effect of moisture content on the popping characteristics of sorghum grain of the three different varieties cultivated in Ukraine. A grain sample of 50 g was conditioned by spraying the grains with a pre-calculated amount of water, then the grains were shaken in a glass container for 1 min for distribution of moisture. Conditioned samples were stored hermetically in a sealed glass container at 16±1°C in a dark place for 48 hours. Microwave popping experiments were performed in a microwave oven (Samsung, Korea) at the operating frequency of 2450 MHz.

All combinations of the pre-treated samples were popped in a glass container placed at the center of the rotating plate in the domestic microwave oven, set at 450, 600, and 700 W for 150 s. The cooking chamber was cooled for 3 min between popping the samples. Popping yield shows the ability of grain to be fully popped during heating (*Mishra et al., 2015*). After the microwave popping, the unpopped grains were handpicked, and the number of total popped grains was recorded. The grains were considered fully popped when they did not have any unpopped parts.

Popping yield (PY) was expressed as following:

$$PY = n_1/(n_1 + n_2 + n_3) \cdot 100 \quad (1)$$

where:

PY is popping yield, [%], n_1 is the number of popped grains, [pcs];

n_2 is the number of semi-popped grains, [pcs];

n_3 is the number of unpopped grains, [pcs].

Sorghum popping start during microwave treatment and allows to estimate the efficiency of applied parameters of the treatment. The popping start was determined during the microwave treatment as an appearance of the first popped grain with a distinct sound of the popping with the use of a stopwatch and was expressed in seconds. Specific weight (SW) was evaluated as the ratio of the weight of popped sorghum grains to the volume of the cylinder filled with the sample of the determined weight using an electronic balance:

$$SW = m/V \quad (2)$$

where:

SW is specific weight, [kg/m^3],

m is the weight of popped grains, [kg];

V is the volume of popped grains, [m^3].

The volume expansion ratio was measured by the sand replacement method (*Joshi et al., 2014a*). The initial volume of 20-40 unpopped pretreated sorghum grains was taken in a 50-ml cylinder and filled with fine sand, and the volume was noted. The same sample was then popped into a microwave oven with the process described in the earlier section. Volume expansion ratio (VER) was calculated using the following expression (*Joshi et al., 2014b*):

$$VER = V_f/V_i \quad (3)$$

Where: VER is the volume expansion ratio (unit); V_f is the final volume of popped sorghum grains, [ml]; Vi is the initial volume of pretreated sorghum grains, [ml].

A sample of the popped sorghum grains was placed on a sheet of white paper under diffused daylight to determine organoleptic characteristics. The shape, color, smell, taste, and structure of the popped grains were estimated by a sensory panel of 9 people familiar with the quality of the grains, mainly academic staff and graduate students of the Faculty of Engineering and Technology. Morphological properties of sorghum grain of different varieties were studied using a scanning electron microscope Jeol JSM-6100 (Jeol, Japan). Grains of sorghum were fractured lengthwise with a razor blade (*Hoseney, 1974*). Pieces of the samples were mounted onto the aluminum stubs, coated with a thin gold film with the help of an ion sputter JFC-1100 (Jeol, Japan), and scanned in the scanning electron microscope at an accelerating voltage of 5 kV. The samples were examined at a magnification of 100, 300, 500 and 1000X and pericarp, germ, aleurone, and translucent endosperm thicknesses were identified. The lengths were measured randomly at different sections of the cut piece image and averaged out for each variety of sorghum grain. All experiment was conducted in triplicate and subjected to analysis of variance (ANOVA) using one-way ANOVA in Microsoft Excel 2016. Means separation was done using Duncan Multiple Range Test and a significant difference was established at $p<0.05$.

RESULTS

The physical and chemical properties of three different varieties of sorghum grain are presented in Table 1. Thousand grain weight of the grain varied between 22 and 32 g. The bulk density was significantly different for the varieties under study ranging from 700 to 870 g/dm^3. This difference is important in the production of popped grains since smaller and medium-sized grains showed better popping yield than larger ones (*Murty et al., 1988*). Usually, sorghum grains have a spherical shape (*Hoseney, 1998*). For example, the Mugad variety (*Mishra et al., 2015*) had the smallest size and sphericity, while the local red variety having bold grains, had the largest size. After microwave treatment, the Mugad grain showed the highest popping yield. The sorghum grain of the Kafrske variety had the smallest size, and the Dniprovsky variety showed the largest size of the grain. The initial moisture content of grain for the different varieties of sorghum varied between 12.3 and 13.0%.

Sorghum grains with such moisture content could be considered dry, and therefore could be stored for long without deterioration of technological properties. The moisture content of sorghum grain ranged from 9.3 to 12.1% (*Mishra et al., 2015*). This initial moisture content was suggested to be too low for the high popping yield of sorghum grains, so preconditioning before microwave heating was strongly recommended (*Mishra et al., 2015; Nathakattur Saravanabavan et al., 2011*). The content of such constituents as protein, ash, and crude fiber varied from 8.03 to 11.67%, 1.35–1.73%, 2.01–5.71%, respectively for the varieties tested. The sorghum grain of the Kafrske variety contained 2–3% more protein compared to the other varieties. The Fulgus variety showed the lowest content of crude fiber. Other researchers studied the popping properties of higher-protein sorghum varieties containing 9.7–9.8% (*Nathakattur Saravanabavan et al., 2011*) and 11.5–12.0% (*Mishra et al., 2015*) protein. Popping yield is one of the main characteristics of popping properties. It determines the efficiency of the use of particular grains for popping production such as ready-to-eat snacks.

Table 1

Some selected physical and chemical properties of sorghum grain varieties

Variety	**Color**	**Thousand grain weight**	**Bulk density**	**Moisture**	**Protein**	**Ash**	**Crude fiber**
		[g/dm^3]	**[g/dm^3]**	**x 10^3 [m^2/kg]**	**[%]**	**[%]**	**[%]**
Dniprovsky	light brown with dark spots	28.1a±0.1	820.3a ±2.0	12.5b±0.1	8.94a ±0.09	1.73a±0.06	5.71a ±0.05
Kafrske	white	22.2b±0.2	700.4b ±2.4	12.3bL±0.1	11.67b ±0.10	1.56b±0.05	4.39b ±0.06
Fulgus	bicolor from light brown to dark brown	31.9c±0.2	869.8c ±2.0	13.0a±0.1	8.03c ±0.11	1.35c±0.02	2.01c ±0.05

Mean ± Standard Deviation (S.D.); different letter represents significant difference (P=0.05), the same letter in a column represents non-significance

Popping yield indicates how many grains can be popped during microwave heating. Fig. 1 presents the popping yield of sorghum grains of different varieties studied depending on the moisture content of the grain before heating and the microwave power during treatment.

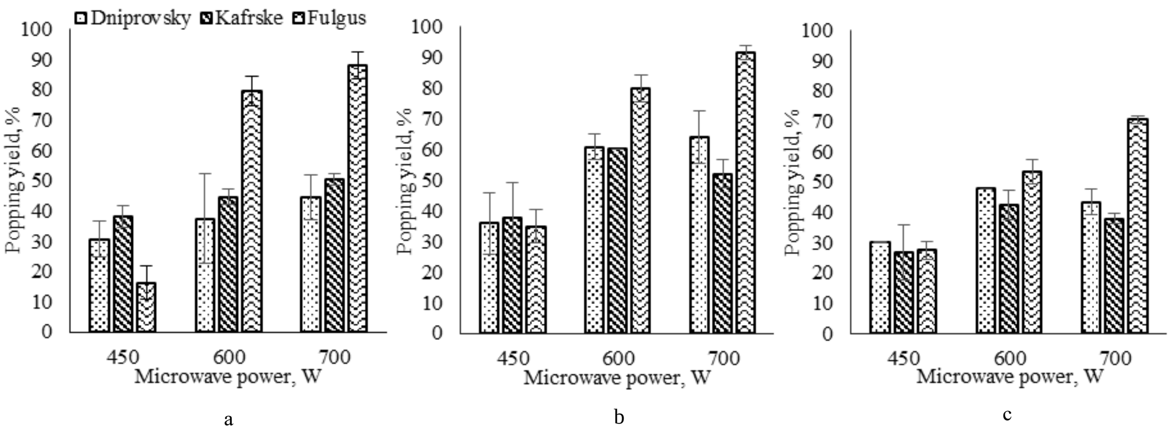

Fig. 1 – Popping yield of sorghum grain of three varieties at the moisture level, %

These processing parameters were taken into account given the previous results obtained by other researchers (*Wu and Schwartzberg, 1992; Mohamed et al., 1993; Farahnaky et al., 2013*). The popping yield of sorghum grains varied from 16.3 to 91.6%. The lowest popping yield was obtained at the microwave power of 450 W and grain moisture content of 13%.

It could be assumed that at low microwave power, there was not enough energy to heat the whole volume of grain, whereas, at a low moisture content of the grain, the water evaporated too rapidly without developing a sufficient level of vapor pressure to expand the grain. However, with the increase of moisture content of grain at the microwave power of 450 W, the difference between the varieties was insignificant. Popping yield at 17–37% was considered to be unsatisfactory (*Mishra et al., 2015*). An increase in microwave processing power up to 600 W caused an increase in the popping yield for the three varieties studied.

Nevertheless, the difference between the Dniprovsky and the Kafrske varieties was insignificant at all levels of moisture content of the grain. These two varieties also showed higher crude fiber and ash content in comparison to the Fulgus variety (Table 2). At microwave power of 600 W, the Fulgus variety had a 25–40% higher popping yield than the other varieties. The popping yield of the Fulgus varied from 16.3 to 91.6% at the moisture content of 13–15% although the increase in the moisture content up to 17% level negatively affected the number of popped grains by microwave heating causing the popping yield to decrease by 20%. The maximum level of microwave power at 700 W induced a significant increase in the popping yield for the Fulgus variety at all levels of moisture content. The highest popping yield was 92 and 64% reached by the Fulgus and the Dniprovsky varieties respectively at a microwave power of 700 W.

Table 2

Characteristics of the anatomical structure of sorghum grain for different varieties

Variety	Pericarp	Aleurone	The translucent endosperm, μm	Germ	
				width	length
	[μm]	[μm]	[μm]	[μm]	[μm]
Dniprovsky	98a ±7	29a±2	481a±41	619a±39	2011a±17
Kafrske	56b±2	13b±1	783b±36	288b±15	488b±3
Fulgus	31c±6	9b±1	1117c±150	350b±55	607c±21

Mean ± Standard Deviation (S.D.); different letter represents significant difference (P=0.05), the same letter in a column represents non-significance

The Kafrske variety performed its best at 600 W, yielding 60% popped sorghum grains. In the study (*Mishra et al., 2015*), the tested sorghum varieties showed the popping yield at 54.2–81.2% at the initial moisture content of 16.5% and microwave processing power of 900 W. Nikolov et al. (*Nikolov et al., 2019*), concluded that the best yield of 85% was achieved at the moisture content of 16%. In our research it was found that the highest popping yield was provided at the moisture content of 15% for the sorghum varieties studied.

Further increase of the moisture content to 17% declined the number of popped grains. Though, the effect of the microwave power on popping yield for the varieties was stronger than the moisture content. Therefore, the best popping yield of the sorghum grain varieties would be achieved with a moisture content of 15% and microwave power of 600–700 W. The duration of microwave heating influences both the energy loss and quality of the popped sorghum. The excessive water evaporation could cause deterioration of the sensory properties due to the burning of popped sorghum (*Bocharova et al, 2012*). The total duration of the microwave heating for the popping was 150 s according to the results obtained before (*Tymchak et al., 2018*). When the microwave heating varied from 100 to 180 s, the highest popping yield was recorded at 140 s of microwave treatment (*Mishra et al., 2015*). Fig. 2 shows that the popping start tended to decrease with the increase of the microwave power at all levels of the moisture content for the sorghum grain varieties studied.

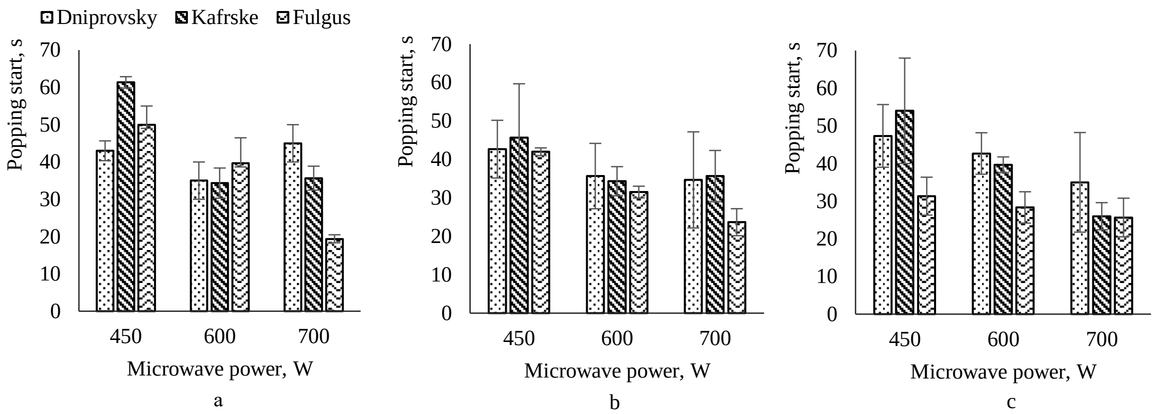

Fig. 2 – Popping start for microwave treated sorghum grain of three varieties at the moisture level, %

The higher microwave power at the heating, the more energy was absorbed by the grain treated (*Hoseney et al., 1983*). This way, enough vapor pressure in the kernel occurred faster to expand the grain. Therefore, the popping start time decreased with the increase of microwave power. At the same time, the Fulgus variety started to pop earlier for 20 s, and the latest one was the Kafrske variety with 62 s of popping started. The duration of the popping start of the Dniprovsky variety varied between 35 and 47 s.

Moreover, the first popped grains continued to absorb the energy by the end of the microwave heating, evaporating moisture, so too fast popping and low moisture content of the grains could cause the product to burn. Otherwise, the late popping induced a low popping yield. The specific weight of popped grains is a qualitative characteristic of the final product. It shows how much of the popped grains are occupied by a given volume. Accordingly, the lower the volume of the popped grains, the better the grains are expanded during the treatment. In general, consumers prefer a higher volume product, and it makes the production profitable (*Wu and Schwartzberg, 1992*). Fig. 3 depicts that the specific weight of the popped grains of the Dniprovsky variety was the most responsive to the moisture content and the microwave power among the sorghum grain varieties studied. Also, we found that the studied parameters of the pretreatment and microwave heating had no significant influence on the specific weight of the popped grains of the Fulgus and the Kafrske varieties at the same microwave power and different moisture content of the grain.

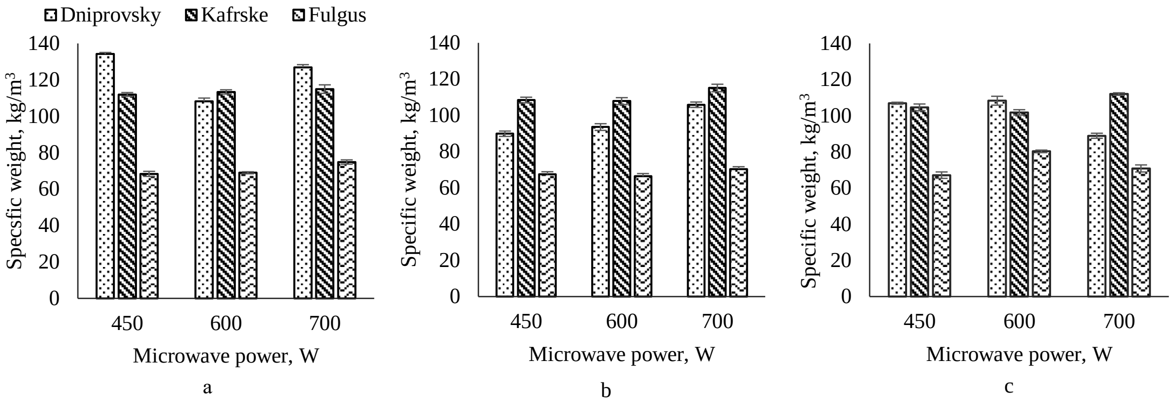

Fig. 3 – Specific weight of popped sorghum grain of three varieties at the moisture level, %

The volume expansion ratio plays an important role in popping properties showing how much the grain can expand during heating. The Kafrske variety was found to have the highest volume expansion ratio ranging from 10 to 14.7 in comparison to other studied varieties of Sorghum bicolor (Fig. 4).

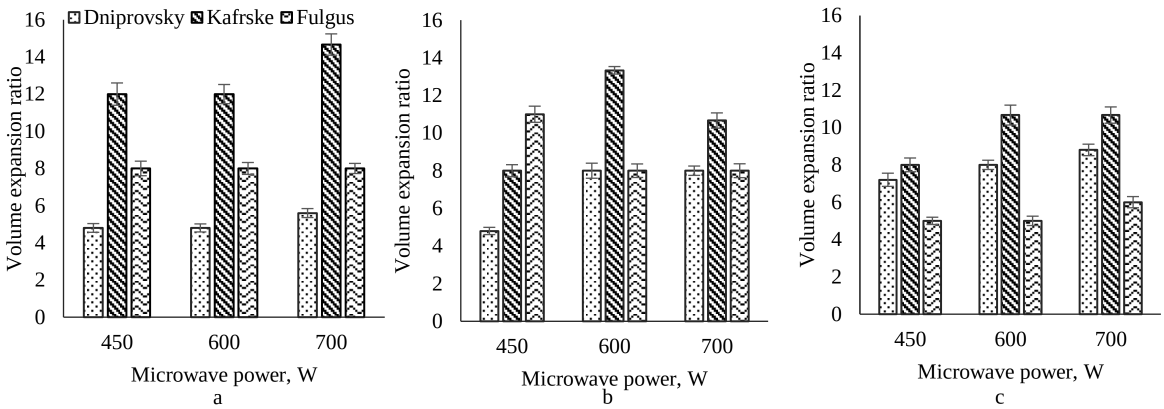

Fig. 4 – Volume expansion ratio of sorghum grain of three varieties at the moisture level, %

This could be caused by the lowest thousand grain weight and small size of grains. Sorghum grains of small or medium size were considered to have a better volume expansion ratio compared to large grains (*Mishra et al., 2015*). However, it was provided opposite results that larger sorghum popped grains were found to be derived from genotypes with a higher thousand seeds weight (*Golubinova et al., 1983; Song et al., 1991*). Moreover, the middle-sized fractions had the highest popping volume and the smallest-sized fractions presented the lowest volume expansion ratio in all varieties of popcorn studied (*Song et al., 1991*).

The Dniprovsky variety showed the lowest volume expansion ratio having intermediate the thousand grain weight and the bulk density of the grain among other varieties. Meanwhile, the Dniprovsky variety had the highest crude fiber and ash content and therefore more outer layers of the grain, which might affect the popping properties (*Mohamed et al., 1993; Hoseney et al., 1983*). The Fulgus variety demonstrated the volume expansion ratio of 5–11.

The best ability of sorghum grain to expand was at the microwave power of 600 and 700 W, except for the Fulgus variety having the highest volume expansion ratio at 450 W of the microwave power. The initial moisture content of the grain was found to be a significant factor in the pretreatment of the Dniprovsky and the Fulgus varieties. The organoleptic properties of popped sorghum are the main indicators of quality to which the consumer's attention is drawn. Also, organoleptic properties are often a limiting factor when using treatment modes, including exposure time and microwave power (*Mishra et al., 2015*). Popped grains of the sorghum varieties cultivated in Ukraine had slightly different color depending on the color of the grain pericarp. Kafrske and Fulgus popped grains had the most neutral taste whereas the Dnipro variety made the popped grains slightly salty aftertaste.

To achieve the best organoleptic properties, the moisture content of the sorghum grain of 15% and the microwave power of 600–700 W was efficient regardless of the sorghum grain variety studied. At the same time, for the Fulgus variety, low moisture content of 13% and the microwave power of 700 W led to the deterioration of the organoleptic properties of the popped grains. The anatomy of grain affects technological approaches to grain processing. The sorghum grain microstructure showed the characteristics of endosperm, germ, aleurone and pericarp depending on the variables studied. The basic anatomical components are pericarp (outer layer), germ (embryo), and endosperm (storage tissue), which took 7.9, 9.8, and 82.3% of the whole grain respectively (*Ratnavathi, 2019*). However, this ratio was known to be affected by the varietal characteristics of the grain. In the varieties studied, the thickness of the pericarp ranged significantly from 31 to 98 µm. This was positively correlated to the ash and crude fiber content, which changed in the following order: Fulgus → Kafrske → Dniprovsky. Despite the thinner pericarp, Fulgus sorghum grain showed high pericarp compactness compared to other varieties. For instance, the thickness of the Dniprovsky variety pericarp was three folds more than for the Fulgus variety, but its structure was loose, having many breaks (Fig. 5).

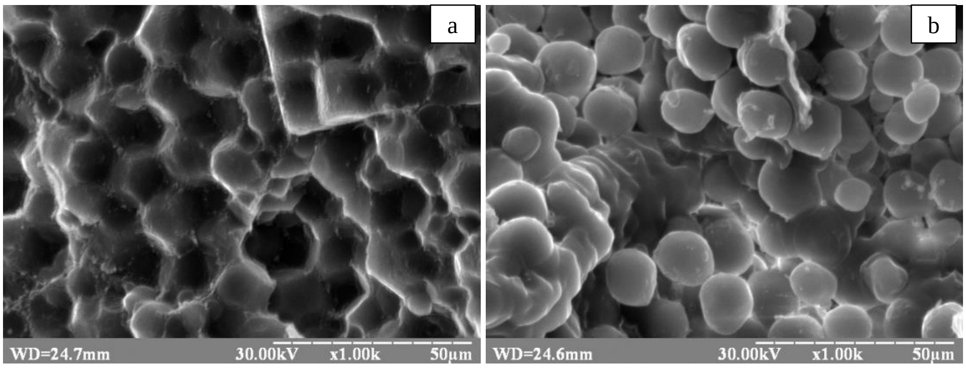

Fig. 5 – Scanning electron microscopy of Fulgus sorghum grain endosperm: translucent (a), opaque (b)

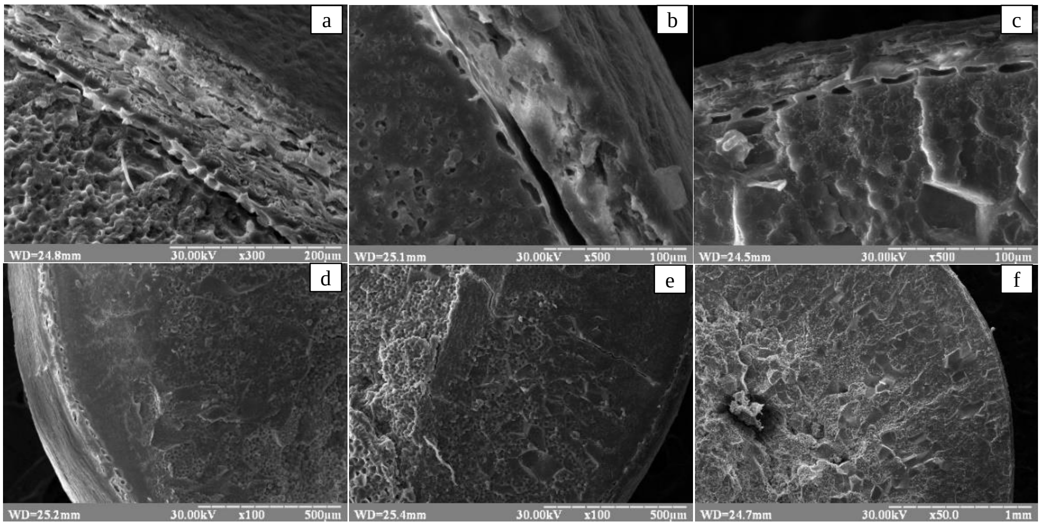

Fig. 6 – Scanning electron microscopy of sorghum grain pericarp (a – c) and endosperm (d – f) for varieties: Dniprovsky (a, d), Kafrske (b, e), Fulgus (c, f)

Scanning electron microscopic study of sorghum grains showed that pericarp thickness played an important role in affecting popping characteristics of sorghum grain; the thinner the pericarp of grains, the poorer was the popping, while grains having thicker pericarp popped well (*Mishra et al., 2015*).

However, good popping characteristics of the Fulgus variety could be explained not by the thickness of the pericarp, but by its density. The Fulgus pericarp structure allowed effectively to generate the necessary level of vapor pressure to expand the endosperm during microwave heating. In sorghum grains as in other cereals, the aleurone layer is the outer layer of the endosperm. Aleurone is an abundant source of albumin-globulin types of protein (*Hoseney, 1998*).

The aleurone layer of the Dniprovsky grain (13 µm) was cracky, irregular, and loose. The Fulgus sorghum grain was found to have the thinnest aleurone layer (9 µm), followed by the Kafrske sorghum grain, showing a definite and regular structure in comparison to the Dniprovsky one. Sorghum grain like corn grain contains translucent and opaque endosperm (*Freire et al., 2020*), the last one is located in the center of the grain. According to the endosperm structure, the Dniprovsky sorghum grain showed the thinnest translucent endosperm layer (487 µm), which is twice less than the Fulgus sorghum grain (1117 µm). The Fulgus variety showing a 1.43-fold increase in the popping yield had thicker translucent endosperm 2.25 times more than the Dniprovsky variety. The thickness of translucent endosperm positively affected the popping characteristics of the sorghum grains. Due to its dense structure, the translucent endosperm acted as a reservoir creating sufficient vapor pressure inside the grain to burst and increased the grain volume due to its structural transformation during microwave heating.

CONCLUSIONS

Sorghum grain could find use in the efficient production of popped products with acceptable quality which depended on particular functional properties of grain and process parameters. A study of three different sorghum varieties (Dniprovsky, Kafrske, Fulgus) showed that protein, ash, crude fiber content, thousand grain weight and bulk density varied significantly among the sorghum grain. The Fulgus variety gave the best response to microwave heating and hence turned out the most promising variety for microwave popping among others. This way popping yield could reach up to 80–90%. High popping yield for the sorghum grain of each variety could be achieved only by using suitable processing modes.

The results of the study provided effective parameters for microwave treatment for the varieties. The moisture content at 15% for the sorghum grain followed by microwave heating at the power of 600–700 W was found to be the best treatment mode for enhancing popping yield, specific weight and organoleptic properties of pop-sorghum for the varieties cultivated in Ukraine.

Scanning electron microscopic study of sorghum grains showed that pericarp thickness and density of its packaging played an important role in affecting popping characteristics of sorghum grain; the thicker pericarp of grains, the poorer was popping, while grains, having thinner and well-packed pericarp, popped well. Sorghum grain with higher crude fiber and ash content, thicker pericarp and aleurone layer showed significantly lower popping yield and higher specific weight of popped grains. The thickness of translucent sorghum endosperm positively correlated with the popping capacity of sorghum grain of the different varieties. The smaller size of the sorghum grains enabled them to increase the volume expansion ratio during microwave popping. Apart from this, large size grain varieties showed an increase in volume expansion ratio from 5 to 9 along with moisture content of the grain raised, whereas small size one demonstrated a decrease of its volume expansion ratio from 15 to 8. The ability to expand was related to crude protein content for the subjected varieties. This study proved that sorghum grain locally cultivated in Ukraine as a perspective climate-resilient crop could have advantages for popped sorghum production, enhance food diversity and also serve as an ingredient in the food industry.

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