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Possibility of sorghum cultivation in Poland and utilisation strategies for sorghum grains and green matter

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Abstract. This review presents a recent review of knowledge on the possibilities of sorghum cultivation in Poland including the strategies for its utilisation. Sorghum is the fifth cereal in the world in terms of production scale. This position stems from high tolerance of this plant to water shortages and, at the same time, relatively good yields. Therefore, the main sorghum growing regions are concentrated in Africa and Asia. In Europe, due to the sufficient supply of consumer and fodder grains of the main cereals (wheat, triticale, rye, oats, and barley), there has been a lack of interest from growers in sorghum cultivation. The plant also has high temperature requirements during the emergence period and requires a long growing season, hence food products from sorghum came from imported grains. Although in Poland the plant still has a small cultivated area, there are visible attempts by growers to cultivate sorghum. The grains can be used more widely in human nutrition, especially for people with gluten intolerance. It is used in livestock feed production. It can be used in the production of bioethanol. In addition to grain production, sorghum can also be grown for green matter, which has applications in ruminant nutrition (cattle, sheep and goats) and biogas production. The aim of this study is to analyse the potential of sorghum cultivation in Poland and the possible directions of cultivation (for grain and green matter) and use (for human food, animal feed and energy purposes). The analysis of the world and Polish literature in the field of sorghum cultivation shows that this species can be cultivated and widely used in Poland. However, it is necessary to popularize the nutritional value and food use of grain in order to build a market. The forage use of both grain and green sorghum mass should also be popularized. The possibility of cultivating sorghum for energy purposes is also a future trend.

Keywords: sorghum, nutritional value, feed value, sorghum cultivation, tannins

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POSSIBILITY OF GROWING SORGHUM IN POLAND

European countries are significant producers of cereal grains, with an annual production of 299.3 million tonnes in European Union countries in 2019 (Eurostat, 2021). The great importance of cereal grains is due to their direct use for human food and for livestock feed. The threat posed by climate change, associated with an increase in average temperature and rainfall deficits, may result in a reduction in the supply of cereal grain and thus in its high price. The example of Poland shows how climate change is progressing. There has been a decrease in the area of the temperate cold region, with an increase in the area of the temperate warm region, and the emergence of a warm region which, according to forecasts, may increase in the future (Ziernicka-Wojtaszek, 2015). These observations also apply to the whole European area, making it necessary to implement adaptation strategies, also in agriculture, to the ongoing climate change (Aguiar et al., 2018). The increase in average temperature and the lengthening of periods favourable to plants with longer vegetation periods promote the possibility of growing thermophilic plants from other climatic zones (Kopeć, 2013). At the same time, with climate change, there is a risk associated with increasingly frequent periods of drought, which negatively affects the yield of cereals, especially spring cereals (Wójcik et al., 2019). Such an extreme drought phenomenon occurred in 2018. It was one of the worst in 21st century Europe in terms of severity, extent and duration. This drought caused significant decreases in crop yields, especially cereals (Thompson et al., 2020). In this context, the introduction of new cereal species for cultivation in Europe may be beneficial. On other continents struggling with water shortages for efficient crop cultivation, sorghum is an alternative to growing more water-demanding cereal species for animal feed (Selle et al., 2018). Also in Poland, increasingly frequent periods of drought pose a threat to stable cereal yields. An alternative seems to be sorghum, which tolerates rainfall deficits well. It is a crop commonly grown in African countries struggling with rainfall deficits (Taylor et al., 2006). Its resistance to rainfall deficits, good yields, as well as the existence of large drought areas in the world, make sorghum the fifth largest crop in terms of acreage grown worldwide, just behind wheat, rice, maize and barley (Wong et al., 2009). The introduction of this species into cultivation in Poland may contribute to a higher supply of sorghum grain on the market, and thus to its wider use. An increase in the area under sorghum cultivation in Europe requires, however, that knowledge about its cultivation be disseminated. Therefore, a number of scientific studies are conducted that focus on proper crop management techniques and cultivation of this plant in different countries. The results of field experiments on the possibility of cultivating sorghum have shown that this cereal can be successfully grown in Europe, both for grain and for green matter. The next stage is their implementation in practice and transfer of knowledge concerning the issues related to effective sorghum cultivation. The critical period of cultivation is the emergence period, which is related to the high thermal requirements and the adjustment of the appropriate sowing date to the climatic conditions of individual countries. In order to initiate the seed germination process, it is necessary for the soil to warm up to above 12 ^{o}C to the depth of 10 cm (Zhang et al., 2020). In Poland, these conditions are usually met after 15 May. According to growers' experience, this is the optimal and safe sowing date (Sus, 2020). Studies conducted on the possibility of grain sorghum cultivation in Poland show that under favourable conditions, when the soil temperature is higher, earlier sowing in the third decade of April is possible. However, it depends on the current weather conditions. The temperature in the sorghum sowing period from the end of April to the second decade of May depends mainly on the changes in the meridional component of the atmospheric circulation. The maximum intensity of its influence falls on May. At this time of the year, the shape of the barric field in the areas located in the north-eastern Poland becomes a factor determining the direction and magnitude of changes in average temperatures (Kożuchowski, Degirmendžić, 2002). Thus, indicators of meridional circulation become the measure of circulation influences on temperature in this period. The role of mean pressure level in shaping thermal conditions also increases – high pressure situations favour insolation and temperature increase.

The results of a study by Sowiński and Szydełko-Rabska (2013) showed that an earlier sowing date can have a beneficial effect on yield, as sowing in the third decade of April resulted in a higher plant density per 1 m^2, which results in obtaining a better yield. Early sowing is justified only if no frost is forecast. The occurrence of a short-term drop in temperature causes the plantation to freeze and the need for re-sowing, which significantly increases costs and brings losses. The study by Kruczek et al. (2014) showed that under Polish climate conditions it is more beneficial to sow sorghum later in the third decade of May. The varied research results show that the sowing date of sorghum in particular years, should be adjusted to the current weather course. The optimum depth should be selected according to soil type. On lighter soils, a sowing depth of 4–7 cm should be used, while on heavier soils a shallower sowing depth of 3–4 cm can be used. Sorghum seeds should not be placed deeper than 7 cm in the soil, as this lowers the plant density (Zou et al., 2019). As stated by Schaffasz et al. (2019), it is possible to select varieties that are less sensitive to cold during the emergence period, hence, according to the researchers, it is possible to adapt certain varieties for cultivation under European climate conditions. Their results show high phenotypic variability and medium to high heritability for most traits, indicating that robust breeding progress is possible. Several varieties available in Europe are well adapted to cooler climates have been identified that can serve as valuable base material for sorghum breeding in temperate areas. From the practice of sorghum growers, seed sowing can be done with precision seed drills with sowing discs with 2–3 mm openings. Such a sowing technique will result in the use of the recommended plant density per hectare of cultivated area. Uniform seed spacing in the row (6–8 cm) will result in the production of main shoots with evenly maturing panicles, which is important for grain sorghum crops. Uneven seed spacing will result in the plant producing a large number of unevenly maturing side shoots, ultimately making it difficult to harvest uniformly mature grain. The recommended sowing rate is 260 000 – 300 000 seeds/ha (6–7 kg) in grain crops under Polish conditions (Sus, 2020). A significant influence on the growth and yield of sorghum has the level of nitrogen fertilisation. The application of a single dose before sowing, limits the emergence of sorghum grains, which reduces the number of plants per unit area (Kruczek et al., 2014). A one-time application of nitrogen in a high dose may result in worse seedling emergence due to the salinity of the soil in the root zone. This causes the death of young seedlings and reduces the number of plants per 1 m^2. The plant density and thus also the grain yield are reduced. Due to row cropping and slow growth at the initial stage, weed infestation is a problem in sorghum cultivation. A problem in cultivation is insufficient availability of herbicides for sorghum plantation protection, which is connected with a small number of plant protection products labelled for use in that crop. Only 5 herbicides were registered and authorised (Matyjaszczyk, 2012). Appropriate herbicide protection of sorghum significantly affects the yield (Nowicka et al., 2019). Under Polish conditions, sorghum yield is also influenced by sowing date as well as weather conditions and soil type. Depending on the soil, grain yield can be 6.0–6.5 t/ha (Sowiński, Szydełko-Rabska, 2013). The economic efficiency of sorghum cultivation also depends on the applied harvesting technology. This is strongly influenced by harvesting conditions. Sorghum starts flowering along with the decreasing day length (in Poland it is mid-July), while it reaches maturity for harvesting at the beginning of October. Most often, then, a significant amount of rainfall adversely affects the quality of the grain (the grain must be dried and it may contain mycotoxins). On the other hand, delaying harvesting causes significant yield losses due to bird feeding (Sowiński, Kuta, 2015). Of particular importance here is the economic efficiency of sorghum cultivation, which depends on the applied harvesting technology. Sorghum panicles can vary in maturity, making it necessary to adapt the harvesting method. Two-stage harvesting provides a higher yield, but increases costs, which negatively affects the rate of return. Single-stage harvesting of sorghum, despite the lower yield, brings higher profit (Sowiński, Kuta, 2015).

FOOD USE OF SORGHUM GRAINS

There are different types of sorghum varieties for different purposes. The sorghum varieties intended for food grain are lower in height. Adult plants reach about 150 cm (Kanbar et al., 2020). For food purposes, sorghum grains are used primarily in the regions where they are grown. This is particularly the case in the dry regions of Africa and India. It is estimated that of the approximately 60 million tonnes of sorghum grain produced annually in the world, 21 million is consumed by humans, with the remainder used for feed (FAO, 1995). Overall, about 35–40% of global sorghum grain production is used for food purposes annually.

The composition of the seeds is dominated by starch, which accounts for 60–80% . It occurs in the form of fractions: amylopectin, which constitutes 70% of its total content and amylose 30%. Protein, depending on the variety and agrotechnical factors (mainly nitrogen fertilisation), is at the level of 7–15 g/100 g. The dominant spare protein in sorghum grain is kafirin, whose percentage of total protein is 42.4 to 57.6% (Salinas et al., 2006). The amino acid profile of sorghum protein contains many essential amino acids. Other components are non-starch polysaccharides (5–10%) and fat (2–6%). The fatty acid profile is dominated by linoleic, oleic and palmitic acids. Many natural carotenoids are dissolved in this fat, including lutein and zeaxanthin, which are quite well absorbed (Moreau et al., 2016) Sorghum grain is also a source of many important minerals such as calcium, phosphorus, iron and zinc. However, the content of these elements in the grain varies and depends on the variety. Since sufficient production of grains of the main bread cereals in Poland fully meets consumer needs, sorghum products are not popular. However, they can be an important alternative for those wishing to limit or exclude gluten from their diet, and in particular for people with intolerance to this protein.

Among sorghum varieties, two types of varieties are distinguished by their tannin content: low and high tannin. Tannins are considered an anti-nutritional ingredient. Their harmful effect lies in the fact that these compounds combine with proteins, with which they form a permanent bond resistant to the action of digestive enzymes proteases. This reduces the digestibility and assimilability of proteins. However, they also have their positive aspect. Scientific research has shown that high-tannin sorghum varieties used in the preparation of meals slow down the passage of digestive content. They cause the food to remain in the stomach for a longer period of time and thus give a prolonged feeling of satiety (Awika, Rooney, 2004). Therefore, they have a low glycemic index and are recommended in the diet of people with diabetes (Dicko et al., 2006). In addition, sorghum grains are a source of fibre, which is desirable in the human diet. Its content in sorghum grains is 6–6.5 g/100 g of seeds (Kołodziejczyk, Michniewicz, 2018). The sterols and polyphenols contained in the grains have a health-promoting effect and in particular support the cardiovascular system (Czerwińska, 2010). Sterols, by binding with cholesterol, hinder fibre absorption into the bloodstream and thus affect its lowering in the blood.

Among the culinary uses, sorghum grains can be used for paste, which can be used to make bread and rolls and other products. White-grained varieties are definitely predisposed to this purpose. A problem in milling of sorghum grains lies in the presence of two hard and soft fractions in its endosperm, as well as brittle seed husks, small particles of which may contaminate the flour fraction and deteriorate the quality of the obtained flour (Zawadzki, 2011). New improved methods of milling sorghum grains are being developed to obtain high quality flour (Zawadzki, 2013). The quality of sorghum flour obtained is also influenced by the variety as well as nitrogen fertilisation (Sobolewska et al., 2018). Nitrogen fertilisation affects the protein content of sorghum grains, which is an important discriminator of its quality. Grains intended for food processing and especially for baking bread should contain a minimum of 11.5% protein in dry matter (Sobolewska, Bury, 2020). Since sorghum grains do not contain gluten, it is impossible to prepare, solely on the basis of the flour obtained from it, a dough with the desired properties for baking. Therefore, in order to obtain a completely gluten-free product based on sorghum flour, it is required to increase the starch content in the dough by adding potato starch and methylcellulose (Czerwińska, 2010). It is then fermented, and after the baking process, bread with the desired sensory properties is obtained. The grains can also be used to prepare porridge, which has good sensory and nutritional properties and is not sticky (Czerwińska, 2010). It is also possible to prepare popcorn from sorghum grains, as from maize. It is also used in multi-grain products such as cereal bars or breakfast cereals. It is also possible to use sorghum seeds for the production of malt, thus succeeding in replacing cereals containing gluten. For economic reasons, the process of malting sorghum seeds is used in countries where it is widely grown and the cost of malting imported cereals is much higher. It is used in brewing to make substitutes of European branch beers (Harasym, Pieciuń, 2010).

FODDER USE OF SORGHUM GRAINS

Sorghum grains are a widely used component of compound feeds, for different groups of livestock. Annually, about 65% of the world production of grain sorghum, is used for feed purposes (Peerzada et al., 2017). Especially in countries with dry and hot climates, where, as one of the few crops, it yields quite well. The fodder value of this cereal and its suitability for use in complete mixtures depends on its feed value. Individual varieties of sorghum have different levels of nutrients, but also substances with anti-nutritional effects. Therefore, varieties with the best possible feed value should be recommended for cultivation for feed grains (Baholet et al., 2018). The high genetic variability among sorghum varieties and its hybrids indicates the possibility of genetic improvement of varieties for higher feed value, including protein and micronutrient content (Badigannavar et al., 2016). One of the most important components in terms of feed value is protein. Sorghum grains contain between 6.6–11.4% of this component, which is determined by the varietal factor (Salinas et al., 2006).

The predominant spare protein in sorghum grains is kafirin, whose percentage of total protein is 42.4 to 57.6% (Salinas et al., 2006). There are many essential amino acids in the amino acid profile of sorghum protein. Kafirin is composed of three fractions: α-kafirin (is relatively the most easily digested form of all kafirins) and accounts for about 82%, and β- and γ-kafirin forms (Selle et al., 2010). Due to the predominance of the more difficult to digest fractions of kafirin in order to improve protein digestibility, the addition of exogenous proteases in compound feeds is justified. Another solution is also the targeted breeding of varieties with reduced kafirin content, which is possible through the identification of suitable sorghum genotypes (Li et al., 2018). It is also possible to produce varieties with much higher lysine content. The sorghum P721Q obtained by Massafaro et al. (2016) is a variety with high lysine content and reduced kafirin content, which in digestibility tests shows four times higher protein digestibility compared to other sorghum varieties.

Sorghum grains have high energy value as they contain 60–80% starch. It occurs in the form of fractions: amylopectin form, which constitutes 70% of its total content and amylose fraction – 30%. The total content of starch in sorghum grains depends on many factors, among others: weather conditions and intensity of cultivation. As reported by Benmoussa et al. (2006) the granularity of starch in sorghum grain and its digestibility can be differentiated by a genetic factor. The researchers concluded that it is possible to breed sorghum varieties in a targeted manner that exhibit increased feed value as a result of higher protein content and higher starch digestibility. This provides the basis for widespread cultivation of varieties with typical forage use and high nutritional efficiency. A correlation between starch digestibility and lower kafirin content, has also been proven. Kafirin surrounding the starch in the endosperm of sorghum grains, hinders its digestibility. However, as proved by Salinas et al. (2006), there is a correlation between the increase in total protein in sorghum grains and a decrease in the content of kafirin Its lower concentration affects the release of starch and increases its digestibility (Liu et al., 2013).

Sorghum grain contains 1.8–4.3% fat, influenced by variety (Moreau et al., 2016; Patekar et al., 2017). Sorghum grains are also a source of natural carotenoids, including lutein and zeaxanthin (Moreau et al., 2016). These carotenoids naturally enhance the colouration of egg yolk and the skin and subcutaneous fat of slaughter birds.

Sorghum grains contain 2% fibre and 1.45 ash. It is a source of many important mineral elements, however, their content in the grains varies and depends on the cultivar. This is confirmed by the results of a study conducted by Badigannavar et al. (2016), who point to the possibility of targeted selection of sorghum cultivars for increased mineral component content. In addition to nutrients, anti-nutrients are present in sorghum grains. These include tannins and phytates. The antinutritional effect of tannins is due to the binding of these compounds with proteins, with which they form a solid bond which is resistant to the action of proteases. This reduces the digestibility of the protein and, as a result, the efficiency of its utilization by the animals. One of the solutions to the problem of tannin content is the breeding and cultivation of varieties with a reduced content of these compounds. Grain of low-tannin varieties contains less tannin than 2.5 g/kg. Phytates, which are also present in the grains of other cereals, are present in sorghum in the amount of 2.66 g/kg of grains which is 77.6% of total phosphorus contained in sorghum grains.

Similarly to other cereals, sorghum is infected by pathogenic fungi of the genus *Fusarium*, which results in mycotoxin contamination of the grains. The mycotoxin content is determined by the weather during the growing season. The same mycotoxins can occur in sorghum as in other cereals. These include aflatoxins, zearaleon, deoxynivalenol, and fumonisins (Table 1). To date, there is no data on the content of individual mycotoxins in domestically grown sorghum grains due to a lack of ongoing research in this direction.

EFFECTIVENESS OF USING SORGHUM GRAINS IN ANIMAL NUTRITION

Sorghum grains are widely used as a feed component for poultry, especially in countries where the cultivation of maize or wheat is not possible due to excessive water deficit. Therefore, most of the research on the possibility of using sorghum in poultry feed mixtures, the usefulness of particular varieties and the maximum share for particular poultry groups comes from the regions of Africa and Asia Minor. The Polish Poultry Nutrition Standards stipulate a maximum share of sorghum grain in feed for layers of up to 20% during rearing and up to 40% during laying, while for turkeys it is 20% (Smulikowska, Rutkowski, 2018). For other production groups and poultry species, there are no designated maximum shares of this sorghum grain as a feed component.

Currently in Poland, sorghum is most often used for feeding, both ornamental and racing, pigeons. It is also a component of mixtures for exotic ornamental birds. Due to the marginal area under sorghum cultivation, there is still no national research into the possibility of using this cereal for feeding productive poultry. In Poland, the vast majority of poultry meat production comes from broiler chickens. The greatest amount of fodder grain in Poland is used for the production of feed for them. So far, triticale has been used most often. However, the introduction of sorghum for grain to cultivation may result in greater utilization of the grain of this cereal for the production of feed for broiler chickens. In view of increasingly frequent droughts and a reduction in grain yield, it may be necessary to replace some of the cereals used to date with cheaper components. One of them may be sorghum grains. As evidenced by the results of the study by Moss et al. (2017), it is possible to effectively rear broiler chickens on compound feeds where part of the wheat was replaced by sorghum. However, according to the authors, it is necessary to use a phytase additive in the feed. The introduction of sorghum in broiler chicken compound feeds is also aimed at improving economic efficiency. In many African countries, sorghum is a substitute for the much more expensive maize. Despite its lower FCR (Feed Conversion Ratio), the use of sorghum in feeds results in lower feed costs and the final economic outcome of fattening is positive. Research shows that it is possible to substitute a significant proportion of maize in feed, especially in grover mixes. This is particularly true for low-tannin sorghum varieties (Mburu et al., 2016). As shown in a study by George et al. (2017), it is possible to use sorghum as a partial substitute for maize in broiler feeds without negative effects on production performance and meat quality.

Table 1. Range of content of individual mycotoxins in sorghum grains (own study based on quoted authors).

Mycotoxin	Range of value (min-max) [μg kg^{-1}]	Author	The highest permissible level [μg kg^{-1}]
Aflatoxins	5.4–61.5	Kange et al. (2015) Chala et al. (2014)	4.0
Zearalenone	45.0–374.0	Oueslati et al. (2014) Chala et al. (2014)	100
Fumonisins	97.0–2041.0	Ediage et al. (2015) Taye et al. (2016)	60
Deoxynivalenol	30.0–78.1	Huerta-Trevino et al. (2016) Chala et al. (2014)	1250

According to Commission Regulation (EU) No. 165/2010

There is also the possibility of using sorghum in the feeding of laying hens. According to a study conducted by Adamu et al. (2017) on the feasibility of using the maximum proportion of sorghum grain in laying hen feed, it was shown that it can be up to 50%. At the same time, by replacing maize with sorghum, the researchers obtained measurable economic benefits. On the other hand, Sriagtula et al. (2019) recommend a maximum of 40% share of sorghum grain in feed for laying hens, which is in line with the recommendations of the Polish Standards of Poultry Nutrition (Smulikowska, Rutkowski, 2018)

Sorghum is also used in the feeding of turkeys for fattening. It is possible to partially substitute cereal grains with sorghum. However, its share should not exceed 25% (Etuk, Ukaejiofo, 2007), which is higher than the value recommended in the Polish Standards of Poultry Nutrition (Smulikowska, Rutkowski, 2018).

It is also possible to use sorghum grains in the feeding of slaughter guinea fowl. A study by Tjetjoo et al. (2013) showed that the feed conversion ratio is higher when sorghum is used than maize with simultanous maintaining of similar slaughter performance.

Substitution of the more expensive maize grains by sorghum in pig feed is also possible. However, there is a need to respect the maximum proportion of sorghum grains in the feed. As established by Pan et al. (2017), for young piglets, the feed should contain a maximum of 20% of sorghum grains and for piglets no more than 40%. Sorghum used as an alternative energy source to maize in diets fed to growing pigs reduces protein utilisation and nitrogen excretion in faeces. However, this problem can be addressed by the addition of exogenous protease enzymes (Pan et al., 2017). Similarly, Pan and Dong (2020) point out the poorer protein utilisation of sorghum grains by pigs, but its energy value is comparable to maize. The possibility of wider use of sorghum in pig feeding depends on the variety and the content of the main anti-nutritional component tannins. Low-tannin varieties have a higher feed value for pigs and are more efficiently utilised by animals (Pan et al., 2019). Other anti-nutritional substances are also contained in sorghum grains, also like trypsin inhibitors, which reduce the activity of digestive enzymes and are responsible for the reduced utilisation of energy and protein from sorghum grain in pigs (Pan et al., 2021). The use of an extrusion treatment for sorghum grain has been shown to have good results. Extruded sorghum grains have a higher energy value and a higher proportion can be used in feed than non-extruded seeds (Rodriguez et al., 2020).

SORGHUM GRAINS AS AN ENERGY SOURCE

Similarly to other cereals, sorghum grains can also be used to produce bioethanol. Global production of bioethanol from sorghum grains is low, with only 4% of the annual crop being used. The energy potential of sorghum grains has been recognized in the United States, where 1/3 of the harvest of this cereal is used for this purpose (Zawadzki, 2015). According to a study by Chmielewska et al. (2014), the efficiency of the ethanol production process from sorghum grains of variety 251 containing high starch content (66.5%) was 54.62– 83.23%. This indicates the possibility of effective bioethanol production from sorghum grain grown under Polish conditions. In order to effectively utilize the potential of sorghum for energy purposes, cultivars with the highest possible yield should be recommended for cultivation. It can be an alternative raw material to the much more expensive maize, and the by-product DDGS can be used as a valuable feedstock. It contains more protein and lower fat content, hence is a more valuable feed raw material than maize DDGS (Zawadzki, 2015).

FODDER USE OF GREEN MATTER FROM SORGHUM

Among sorghum varieties, we can distinguish those which are characterised by a significant increase in vegetative weight (i. e. a taller plant stature). They are referred to as silage varieties because the green matter is usually preserved by ensiling. The nutritional value of the obtained sorghum silage depends on the variety. Cultivars with a high amount of green biomass and a small amount of grain have a lower forage value. The varieties characterized by a high degree of green mass accumulation, and at the same time giving an appropriate grain yield, have a better forage value. It is related to the increased content of starch (Veriato et al., 2018). Particularly useful for the production of silage for dairy cows is midrib sorghum, the silage of which has the same nutritional value as maize silage (Sánchez-Duarte et al., 2019). Sorghum silage is mainly used for ruminants, but it can also be used for horses. Sorghum silage has a lower nutritive value than maize, but sorghum has the advantage of being more drought resistant than maize and has a higher yield of green matter in the dry period. Research shows that there is scope for targeted breeding of drought tolerant sorghum varieties that can simultaneously deliver significant green matter yield. Habyarimana et al. (2004) identified high yielding and drought tolerant genotypes that can be directly used for biomass production. High hybrid performance under water deficit conditions may be of interest in developing drought tolerant sorghum cultivars to increase and stabilize biomass production. Under Polish climate conditions, different varieties produce different amounts of biomass. Therefore, the selection of a suitable variety is crucial for the success and effectiveness of cultivation for the production of silage for animals. It is also important to maximise the proportion of ensiling plant parts such as leaves. In a study by Nowicka and Waligóra (2020), different sorghum cultivars grown for silage showed a different share of stems and leaves, when grown under the same conditions.

The ensiled green mass of sorghum, as well as maize silage can be used for feeding beef and dairy cattle. Feeding fodder sorghum silage, appropriately supplemented with maize meal as a complete replacement for maize silage, ensured milk yield and feed efficiency, understood as the ability of the cows to convert feed into milk. Replacing maize silage with sorghum silage did not change the concentration of saturated and monounsaturated fatty acids, but reduced the content of polyunsaturated fatty acids in milk. Furthermore, n-6 and n-3 fatty acids were lower in the milk of cows fed a sorghum diet compared to cows fed a maize diet. Replacing maize silage with sorghum silage in dairy cows did not change the milk coagulation properties, which are of great economic importance for the Italian dairy industry. These preliminary results suggest that forage sorghum silage may have potential as a substitute for maize silage in the diet of dairy cows Cattani et al., 2017). Also, Polish studies have shown that whole plant sorghum silage, can be an alternative to maize silage in areas threatened by frequent soil drought. In cattle fed a forage based on sorghum silage and grass silage at the same time, milk yield was good as in the group that was fed maize silage (Śliwiński et al., 2013). Also in lamb fattening, it is possible to replace maize silage with sorghum silage. The use of sorghum silage in the lamb ration does not deteriorate the post-slaughter quality of carcasses compared to maize silage (Grabowicz et al., 2013).

The production of green fodder for ensiling and feeding to animals is important in countries where there is a shortage of rainfall or where it is necessary to maximise the production of green fodder from a small area of arable land. An example of this is Brazil, where there is a dry season when rainfall deficits prevent the production of green matter for animals. Therefore, research has been undertaken into the possibility of growing sorghum and using the silage from its green matter in horse feed. Mangalarga Marchador (MM) mares were weaned and randomly assigned to one of 2 groups with 7 foals in each: GS: fed with sorghum silage (Sorghum bicolor variety BRS655) or GH: fed with Vaquero grass hay (Cynodon variety CD90160 × cv. Mirage). Both groups received a commercially available concentrate daily at 1.5% body weight (BW) in dry matter. The results show that the growth and development of the fillies in both groups of the experiment was breed appropriate. The use of sorghum silage for fillies aged 6 to 9 months, which receive an additional 1.5% BW of a concentrate balanced for growing horses in the dry season, allowed normal growth and development of young horses (da Silva Inácio et al., 2018b). Sorghum silage can be used as an alternative to other roughages for horses, which they also receive. Sorghum silage did not adversely affect the body and health development, but it cannot be used without the addition of concentrated feed and when feeding for a longer period (da Silva Inácio et al., 2018a).

SORGHUM BIOMASS AS AN ENERGY SOURCE

Plants with rapid growth and green mass accumulation are also predisposed to use as renewable energy sources. In recent years, numerous studies have been undertaken on the use of various crop species for energy purposes. Green plant biomass is the least capital intensive source of green energy. It is produced all the time in every place on earth and it is practically a spontaneous process, which takes place naturally by means of photosynthesis of plants. The carbon compounds accumulated in the green mass are the subsequent substrate for biogas production. At present, the share of energy obtained from biomass is 15% of global consumption. This share is higher in developing countries, where it amounts to 38% of total energy production. Production of biomass in many countries, including Poland, is becoming an important branch of agriculture – it allows for waste management and also opens up the possibility of cultivation for energy purposes only. For this purpose, attempts are being made to use many species of plants, with grasses being the most effective. Among these, those with C4-type photosynthesis such as maize and sorghum play an important role. Sorghum has lower water requirements than maize, but its cultivation for biogas is less efficient compared to maize. Szempliński et al. (2014), found that sorghum had a lower efficiency compared to maize by 40%. However, the sorghum crop was 14% more efficient than Virginia mallow. Other researchers showed the opposite relationship, as they obtained a higher green matter yield of sorghum, but they used row fertilisation (Kruczek et al., 2014). The efficiency of energy use of sorghum green mass depends on the appropriate selection of the variety. This is determined not only by the efficiency of green mass production, but also of starch-rich grain. Dual purpose grades with high starch content have the potential to achieve a similar or higher methane yield compared to maize (Windpassinger et al., 2015). A good solution for higher green matter production is the simultaneous cultivation of maize and sorghum in mix cropping technology. Appropriate selection of maize and sorghum varieties gives a high yield of green biomass (Michalski et al., 2017). In mixed cropping of sorghum and maize, the yield of green matter is comparable to or slightly lower than that of pure sowing of maize. The energy yield expressed in terms of the efficiency of biogas and methane obtained per hectare of cultivation is sometimes higher, especially when hybrids of sugar sorghum are intercropped with maize (Grabovskyi et al., 2021)

CONCLUSION

In Poland, sorghum is a cereal with marginal acreage cultivation and low potential utilisation. However, there is a perspective of introducing and popularising the cultivation of this cereal. Since droughts are more and more frequent in Poland and, as a result, unstable and lower yields of cereals, they may contribute to increased interest in alternative cereal species. Sorghum, which comes from a warm climate, tolerates water shortages in the soil and high temperatures quite well without a significant reduction in grain yield. Another advantage of this cereal is the multi-purpose use of its grains. It can be used for food purposes. Particularly among the growing group of consumers with gluten intolerance, but also among people who care about a varied diet. The possibility of using sorghum grains for fodder purposes may diversify the fodder grain base in Poland, which is extremely important in view of the challenges of adapting modern agriculture to climate change. Another direction of grain use is the production of bioethanol, which is also one of the possible directions of grain use of this cereal. Green sorghum can replace the cultivation of maize in sandy soils with a lower water-retaining capacity. Therefore, the cultivation of sorghum for green mass makes it possible to produce green fodder for ruminants (mainly cattle, especially dairy). The production of biogas is also a potential direction for the use of green biomass.

REFERENCES

Adamu N., Doma U. D., Abubakar M., Muhammad A.S., Sani I., 2017. Performance of laying chickens fed dietary levels of red sorghum variety (Sorghum bicolor (L.)). Journal of Animal Production Research, 29(2): 35-42.

Aguiar F.C., Bentz J., Silva J.M., Fonseca A.L., Swart R., Santos F.D., Penha-Lopes G., 2018. Adaptation to climate change at local level in Europe: An overview. Environmental Science & Policy, 86: 38-63, doi: 10.1016/j.envsci.2018.04.010.

Awika J.M., Rooney L.W., 2004. Sorghum phytochemicals and their potential impact on human health. Phytochemistry, 65(9): 1199-1221, doi: 10.1016/j.phytochem.2004.04.001.

Badigannavar A., Girish G., Ramachandran V., Ganapathi T.R., 2016. Genotypic variation for seed protein and mineral content among post-rainy season-grown sorghum genotypes. The Crop Journal, 4(1): 61-67, doi: 10.1016/j.cj.2015.07.002.

Baholet D., Mrvova K., Horky P., Pavlata L., 2018. Comparison of nutrient composition of sorghum varieties depending on different soil types. NutriNet, 24: 77-85 (available online at:

https://pdfs.semanticscholar.org/61a5/3a2fb7e6582b3f5940d29f4e0c48f43e4c11.pdf).

Benmoussa M., Suhendra B., Aboubacar A., Hamaker B.R., 2006. Distinctive sorghum starch granule morphologies appear to improve raw starch digestibility. Starch - Stärke, 58(2): 92, doi: 10.1002/star.200400344.

Cattani M., Guzzo N., Mantovani R., Bailoni L., 2017. Effects of total replacement of corn silage with sorghum silage on milk yield, composition, and quality. Journal of Animal Science and Biotechnology, 8(1): 1-8, doi: 10.1186/s40104-017-0146-8.

Chala A., Taye W., Ayalew A., Krska R., Sulyok M., Logrieco A., 2014. Multimycotoxin analysis of sorghum (Sorghum bicolor L. Moench) and finger millet (Eleusine coracana L. Garten) from Ethiopia. Food Control, 45: 29-35, doi: 10.1016/j.foodcont.2014.04.018.

Chmielewska J., Dziuba E., Foszczyńska B., Sowiński J., 2014. Sorghum grain as raw material for bioethanol production. Przemysł Chemiczny 8(93): 1390-1392, doi: 10.12916/przemchem.2014.1390. [in Polish +summary in English]

Czerwińska D., 2010. Walory żywieniowe i możliwości wykorzystania sorgo w żywieniu człowieka. Przegląd Zbożowo-Młynarski, 11(54): 13-14.

da Silva Inácio D.F., de Rezende A.S.C., Melo M.M., Lana Â.M.Q., Silva R.H.P., de Jesus Mendes L., Gonçalves Reisa L.P., Maruch S., Ralston S.L., 2018a. Effect of supplementation of sorghum silage in weanling fillies during the dry period in Brazil. Journal of Equine Veterinary Science, 68: 88-93, doi: 10.1016/j.jevs.2018.05.217.

da Silva Inácio D.F., de Rezende A.S.C., Silva R.H.P., Melo M.M., de Jesus Mendes L., Maruch S., da Costa Marcelos K., Quintão L.A., Ralston S.L., 2018b. The use of sorghum silage in feeding weanling horses: Body development. Livestock Science, 215: 46-48, doi: 10.1016/j.livsci.2017.09.025

Dicko M.H., Gruppen H., Traoré A.S., Voragen A.G., Van Berkel W.J., 2006. Sorghum grain as human food in Africa: relevance of content of starch and amylase activities. African Journal of Biotechnology, 5(5): 384-395 (available online at: https://www.ajol.info/index.php/ajb/article/view/137858).

Ediage E.N., van Poucke C., de Saeger S., 2015. A multi-analyte LC-MS/MS method for the analysis of 23 mycotoxins in different sorghum varieties: The forgotten sample matrix. Food Chemistry, 177: 397-404, doi: 10.1016/j.foodchem.2015.01.060.

Etuk E.B., Ukaejiofo U.R., 2007. Tannin content and dietary effects of brown coat coloured sorghum on the performance of young local turkey. Animal Production Research Advances, 3(2): 86-90, doi: 10.4314/apra.v3i2.36372.

EUROSTAT 2021. https://ec.europa.eu/eurostat/statisticsexplained/index.php?title=File:Production_of_cereals_by_main_producing_Member_States_2021_(%25_share_of_EU27_totals)_AFF2020.png

Food and Agricultural Organization FAO, 1995. Sorghum and millet in human nutrition. FAO Food Nutr Ser, Rome; 27.

George A., Habeanu M., Olteanu M., Turku P.R., Dragomir K., 2017. Effects of dietary sorghum and triticale on performance, carcass traits and meat pH in broiler chickens. Food Feed Research, 44 (2): 181–187 (available online at: http://scindeks.ceon.rs/Article.aspx?artid=2217-53691702181G).

Grabovskyi M., Lozinskyi M., Grabovska T., Roubík H., 2021. Green mass to biogas in Ukraine—bioenergy potential of corn and sweet sorghum. Biomass Conversion and Biorefinery, 1-9, doi: 10.1007/s13399-021-01316-0.

Grabowicz M., Zaremba I., Szterk P., Dorszewski P., 2013. Effect of sorghum silage on performance of fattening lambs. XLIInd Scientific Conference CAN CAS PAS Bydgoszcz, 18-20.09.2013 (avaliable at: https://www.researchgate.net/profile/Piotr-Dorszewski/publication/264772444_Effect_of_sorghum_silage_on_performance_of_fattening_lambs/links/53ee686a0cf26b9b7dc9f823/Effect-of-sorghum-silage-on-performance-of-fattening-lambs.pdf)

Habyarimana E., Laureti D., De Ninno, M., Lorenzoni C., 2004. Performances of biomass sorghum [Sorghum bicolor (L.) Moench] under different water regimes in Mediterranean region. Industrial Crops and Products, 20(1): 23-28, doi: 10.1016/j.indcrop.2003.12.019

Harasym J., Pieciuń T., 2010. Atypical brewing malts – a reviev. Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu. Nauki Inżynierskie i Technologie, 92: 77-91 (avaliable online at: https://www.researchgate.net/profile/Joanna-Harasym/publication/280088670_Nietypowe_slody_piwowarskie_-_przeglad_Atypical_brewing_malts_-_review/links/55a7b6a808ae7837c65ce3d1/Nietypowe-slody-piwowarskie-przeglad-Atypical-brewing-malts-review.pdf). [in Polish+summary in English]

Huerta-Trevino A., Davila-Avina J., Sánchez E., Heredia N., García S., 2016. Occurrence of mycotoxins in alfalfa (Medicago sativa L.), sorghum [Sorghum bicolor (L.) Moench], and grass (Cenchrus ciliaris L.) retailed in the state of Nuevo Leon, México. Agrociencia, 50: 825-836 versión On-line ISSN 2521-9766 (available online at: http://www.scielo.org.mx/scielo.php?pid=S1405-31952016000700825&script=sci_arttext&tlng=en).

Kanbar A., Shakeri E., Alhajturki D., Horn T., Emam Y., Tabatabaei S. A., Nick, P., 2020. Morphological and molecular characterization of sweet, grain and forage sorghum (Sorghum bicolor L.) genotypes grown under temperate climatic conditions. Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology, 154(1): 49-58, doi: 10.1080/11263504.2019.1569568.

Kange A. M., Cheruiyot E. K., Ogendo J. O., Peter F., 2015. Effect of sorghum [Sorghum bicolor (L.) Moench] grain conditions on occurrence of mycotoxin-producing fungi. Agriculture & Food Security, 4: 15-23, doi: 10.1186/s40066-015-0034-4.

Kołodziejczyk P., Michniewicz J., 2018. Cereal grains and cereal products as sources of dietary fibre. Żywność Nauka Technologia Jakość, 25(3): 5-22, doi: 10.15193/ZNTJ/2018/116/242. [in Polish+summary in English]

Kopeć B., 2013. Thermal conditions in Poland and the possibility of cultivating thermophilic plants. Praca doktorska (PhD thesis), Katedra Ekologii, Klimatologii i Ochrony Powietrza, Uniwersytet Rolniczy im. H. Kołłątaja w Krakowie. [in Polish + summary in English]

Kożuchowski K., Degirmendžić J., 2002. Wskaźniki cyrkulacji a temperatura powietrza w Polsce. In: Oscylacja Północnego Atlantyku i jej rola w kształtowaniu zmienności warunków klimatycznych i hydrologicznych Polski; ed. A.A. Marsz, A. Styszyńska, Akademia Morska w Gdyni. [in Polish]

Kruczek A., Skrzypczak W., Waligóra H., 2014. Comparison of yielding of maize and sorghum grown with different methods by two ways of fertilization with nitrogen-phosphorus fertilizer. Nauka Przyroda Technologie, 8(1): 1-12 (avaliable online at: https://www.cabdirect.org/cabdirect/abstract/20143175461). [in Polish +summary in English]

Li A., Jia S., Yobi,A., Ge Z., Sato S. J., Zhang C., Angelovici R., Clemente T.E., Holding D.R., 2018. Editing of an alpha-kafirin gene family increases, digestibility and protein quality in sorghum. Plant Physiology, 177(4): 1425-1438, doi: 10.1104/pp.18.00200.

Liu S.Y., Selle P.H., Cowieson A.J., 2013. Strategies to enhance the performance of pigs and poultry on sorghum-based diets. Animal Feed Science and Technology, 181(1-4): 1-14, doi: 10.1016/j.anifeedsci.2013.01.008.

Massafaro M., Thompson A., Tuinstra M., Dilkes B., Weil C. F., 2016. Mapping the increased protein digestibility trait in the high-lysine sorghum mutant P721Q. Crop Science, 56(5): 2647-2651, doi: 10.2135/cropsci2016.03.0188.

Matyjaszczyk E., 2012. Current possibilities of selected minor crops protection in Poland and other European Union countries Aktualne możliwości ochrony wybranych upraw małoobszarowych w Polsce i innych państwach Unii Europejskiej. Progress in Plant Protection /Postępy w Ochronie Roślin, 52 (1): 167-173. [in Polish + summary in English]

Mburu J.N., Gicheha J.G., Kabuage L.W., Njonge F.K., Owino W.O., 2016. Growth and carcass traits in broiler chicken fed on low-tannin grain sorghum in Kenya. In: Fifth African Higher Education Week and RUFORUM Biennial Conference: Linking agricultural universities with civil society, the private sector, governments and other stakeholders in support of agricultural development in Africa, Cape Town, South Africa, 17-21 October 2016, pp. 755-761.

Michalski T., Kowalik I., Szulc P., Waligóra H., Sobieszczański R., 2017. Yielding and plant structure of maize intercropped with sorghum. Journal of Research and Applications in Agricultural Engineering, 62(4): 18-24 (available online at: http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.baztech-5c762b1e-bf51-450b-82e2-149fc3da84dc).

Moreau R.A., Harron A.F., Powell M.J., Hoyt J.L., 2016. A comparison of the levels of oil, carotenoids, and lipolytic enzyme activities in modern lines and hybrids of grain sorghum. Journal of the American Oil Chemists' Society, 93(4): 569-573, doi: 10.1007/s11746-016-2799-4.

Moss A.F., Sydenham C.J., Truong H.H., Liu S.Y., Selle P.H., 2017. The interactions of exogenous phytase with whole grain feeding and effects of barley as the whole grain component in broiler diets based on wheat, soghum and wheat-sorghum blends. Animal Feed Science and Technology, 227: 1-12, doi: https://doi.org/10.1016/j.anifeedsci.2017.02.013.

Nowicka S., Waligóra H., Skrzypczak W., 2019. Efficiency of some herbicides for weed control in sorghum. Biuletyn Instytutu Hodowli i Aklimatyzacji Roślin, 287: 45-46. [in Polish + summary in English]

Nowicka S., Waligora, H., 2020. The evaluation of sorghum varieties yield in Wielkopolska conditions. Fragmenta Agronomica, 37(1): 32-37 (available online at: https://pta.up.poznan.pl/pdf/2020/5%20FA%2037(1)%202020%20Nowicka.pdf). [in Polish+ summary in English]

Oueslati S., Jesús B., Juan C.M., Abdelwahed G., Jordi M., 2014. Presence of mycotoxins in sorghum and intake estimation in Tunisia. Food Additives & Contaminants: Part A., 31: 307-318, doi: 10.1080/19440049.2013.867367.

Pan L., Dong A., 2020. Nitrogen utilization is lower for sorghum-based diets compared with corn-based diets in pigs. Livestock Science, 237, 104066, doi: 10.1016/j.livsci.2020.104066.

Pan L., An D., Zhu W.Y., 2021. Sorghum as a dietary substitute for corn reduces the activities of digestive enzymes and antioxidant enzymes in pigs. Animal Feed Science and Technology, 273, 114831, doi: 10.1016/j.anifeedsci.2021.114831.

Pan L., Ma X., Hu J., Liu L., Yuan M., Liu L., Defa L., Piao X., 2019. Low-tannin white sorghum contains more digestible and metabolisable energy than high-tannin red sorghum if fed to growing pigs. Animal Production Science, 59(3): 524-530, doi: 10.1071/AN17245.

Pan L., Shang Q.H., Wu Y., Ma X.K., Long S.F., Liu L., Li D.F., Piao X.S., 2017. Concentration of digestible and metabolizable energy, standardized ileal digestibility, and growth performance of pigs fed diets containing sorghum produced in the United States or corn produced in China. Journal of Animal Science, 95(11): 4880-4892, DOI: 10.2527/jas2017.1859.

Patekar S., Moreand D., Hashmi S., 2017. Studies on physicochemical properties and minerals content from different sorghum genotypes. Journal of Pharmacognosy and Phytochemistry, 6(5): 600-604 (available online at: https://www.phytojournal.com/archives/2017/vol6issue5/PartI/6-4-417-889.pdf).

Peerzada A.M., Ali H.H., Chauhan B.S., 2017. Weed management in sorghum [Sorghum bicolor (L.) Moench] using crop competition: A review. Crop Protection, 95: 74-80, doi: 10.1016/j.cropro.2016.04.019.

Rodriguez D.A., Lee S.A., Jones C.K., Htoo J.K., Stein H.H., 2020. Digestibility of amino acids, fiber, and energy by growing pigs, and concentrations of digestible and metabolizable energy in yellow dent corn, hard red winter wheat, and sorghum may be influenced by extrusion. Animal Feed Science and Technology, 268, 114602, doi: 10.1016/j.anifeedsci.2020.114602.

Salinas I., Pro A., Salinas Y., Sosa E., Becerril C.M., Cuca M., Cervantes M., Gallegos J., 2006. Compositional variation amongst sorghum hybrids: Effect of kafirin concentration on metabolizable energy. Journal of Cereal Science, 44: 342-346, doi: 10.1016/j.jcs.2006.08.008.

Sánchez-Duarte J.I., Kalscheur K.F., García A.D., Contreras-Govea F.E., 2019. Meta-analysis of dairy cows fed conventional sorghum or corn silages compared with brown midrib sorghum silage. Journal of dairy science, 102(1): 419-425, doi: 10.3168/jds.2018-14552.

Schaffasz A., Windpassinger S., Friedt W., Snowdon R., Wittkop B., 2019. Sorghum as a novel crop for Central Europe: Using a broad diversity set to dissect temperate-adaptation. Agronomy, 9(9):535, doi: 10.3390/agronomy9090535.

Selle P.H., Cadogan D.J., Li X., Bryden W.L., 2010. Implications of sorghum in broiler chicken nutrition. Animal Feed Science and Technology, 156(3-4): 57-74, doi: 10.1016/j.anifeedsci.2010.01.004.

Selle P.H., Moss A.F., Truong H.H., Khoddami A., Cadogan D.J., Godwin I.D., Liu S.Y., 2018. Outlook: Sorghum as a feed grain for Australian chicken-meat production. Animal Nutrition, 4(1): 17-30, doi: 10.1016/j.aninu.2017.08.007.

Śliwiń**ski B., Brzóska F., Węglarzy K., 2013.** Effect of sugar sorghum silage in comparison to maize silage in PMR ration on cows' yield, milk composition and blood serum parameters. Roczniki Naukowe Zootechniki, 40(2): 155-169 (available online at: https://rnz.izoo.krakow.pl/files/RNZ_2013_40_2_art06.pdf. [in Polish+ summary in English]

Smulikowska S., Rutkowski A. (eds) (2018). Standards and Recommendations of Poultry Nutrition (2005). Recommended allowances and nutritive value of feedstuffs. In: Poultry Feeding Standards, 4th edn. The Kielanowski Institute of Animal Physiology and Nutrition, PAS, Jablonna (Poland)

Sobolewska M., Bury M., 2020. Sorghum flour – its properties and composition. Przegląd Zbożowo-Młynarski, 4: 18-19. [in Polish+ summary in English]

Sobolewska M., Jaroszewska A., Bury M., 2018. The effect of nitrogen fertilization on amylographic properties of sorghum flour. Przegląd Zbożowo-Młynarski 6 (62): 32-33. [in Polish+ summary in English]

Sowiński J., Kuta L., 2015. Economic analysis of grain sorghum cultivation depending on harvesting methods. Zeszyty Naukowe Szkoły Głównej Gospodarstwa Wiejskiego. Ekonomika i Organizacja Gospodarki Żywnościowej, 110: 191-203 (available online at: https://agro.icm.edu.pl/agro/element/bwmeta1.element.agro-f3f55293-3780-46c7-8b6c-f7582dc06590). [in Polish+ summary in English]

Sowiński J., Szydełko-Rabska E., 2013. Grain sorghum variety 251, cultivation possibility at Lower Silesia environment conditions – introduction research. Fragmenta Agronomica, 30 (4): 138-146. [in Polish + summary in English]

Sriagtula R., Djulardi A., Yuniza A., Wizna Z., 2019. Effects of the substitution of corn with sorghum and the addition of indigofera leaf flour on the performance of laying hens. Advances in Animal and Veterinary Sciences, 7(10): 829-834 (available online at: http://nexusacademicpublishers.com/uploads/files/AAVS_7_10_829-834.pdf).

Sus J., 2020. Sorgo ziarnowe w Polsce. Fauna & Flora, 4(255): 21-22. [in Polish]

Szempliński W., Parzonka A., Salek T., 2014. Yield and energy efficiency of biomass production of some species of plants grown for biogas. Acta Scientiarum Polonorum. Agricultura, 13(3): 67-80 (available online at: http://old-agricultura.acta.utp.edu.pl/index.php?page=abstrakt&lg=en&id=54&id2=455).

Taye W., Ayalew A., Chala A., Dejene M., 2016. Aflatoxin B1 and total fumonisin contamination and their producing fungi in fresh and stored sorghum grain in east Hararghe, Ethiopia. Food Additives & Contaminants: Part B., 9: 237-245, doi: 10.1080/19393210.2016.1184190.

Taylor J.R.N., Schober T.J., Bean S.R., 2006. Novel food and non-food uses for sorghum and millets. Journal of Cereal Science, 44(3): 252-271, doi: 10.1016/j.jcs.2006.06.009.

Thompson R.L., Broquet G., Gerbig C., Koch T., Lang M., Monteil G., Rödenbeck C., 2020. Changes in net ecosystem exchange over Europe during the 2018 drought based on atmospheric observations. Philosophical Transactions of the Royal Society B, 375(1810), 20190512, doi: 10.1098/rstb.2019.0512.

Tjetjoo S.U., Moreki J.C., Nsoso S.J., Madibela O.R., 2013. Growth performance of guinea fowl fed diets containing yellow maize, millet and white sorghum as energy sources and raised under intensive system. Pakistan Journal of Nutrition, 12: 306-312 (available online at: http://moodle.buan.ac.bw:80/handle/123456789/163).

Veriato F.T., Pires D.A., Tolentino D.C., Alves D.D., Jayme D.G., Moura M.M.A., 2018. Fermentation characteristics and nutritive values of sorghum silages. Acta Scientiarum. Animal Sciences, 40, doi: 10.4025/actascianimsci.v40i1.34458.

Windpassinger S., Friedt W., Frauen M., Snowdon R., Wittkop B., 2015. Designing adapted sorghum silage types with an enhanced energy density for biogas generation in temperate Europe. Biomass and Bioenergy, 81: 496-504, doi: 10.1016/j.biombioe.2015.08.005.

Wójcik I., Doroszewski A., Wróblewska E., Koza P., 2019. Agricultural drought in the cultivation of spring cereals in Poland in 2006–2017. Woda-Środowisko-Obszary Wiejskie, Water-Environment-Rural Areas, 19: 77-95 (available online at: https://www.itp.edu.pl/old/wydawnictwo/woda/zeszyt_65_2019/Wojcik%20i%20in.pdf).

Wong J.H., Lau T., Cai N., Singh J., Pedersen J.F., Vensel W.H., Hurkman W.J., Wilson J.D., Lemaux P.G., Buchanan B.B., 2009. Digestibility of protein and starch from sorghum (Sorghum bicolor) is linked to biochemical and structural features of grain endosperm, Journal of Cereal Science, 49: 73-82, doi: 10.1016/j.jcs.2008.07.013.

Zawadzki K., 2011. Badania nad przemiałem sorgo i możliwością wykorzystania uzyskanej mąki w produkcji pieczywa bezglutenowego. Przegląd Zbożowo-Młynarski, 1(55):11. [in Polish]

Zawadzki K., 2013. Mąka z sorgo coraz popularniejszym składnikiem produktów bezglutenowych. Przegląd Zbożowo-Młynarski, 10(57):18. [in Polish]

Zawadzki K., 2015. Sorgo – zboże o szerokich możliwościach wykorzystania. Przegląd Zbożowo-Młynarski, 7(59):19. [in Polish]

Zhang R.D., Xiao M.Y., Xu X.X., Jiang B., Yi-Fan X.F, Chen X.F., Li B., Ai X.Y., Huang R. D., 2020. Responses of sorghum hybrids to germination temperatures and identification of low temperature resistance. Acta Agronomica Sinica, 46(6): 889-901, doi: 10.3724/SP.J.1006.2020.94150.

Ziernicka-Wojtaszek A., 2015. Climatic water balance in Poland in the light of the present day climate change. Woda-Środowisko-Obszary Wiejskie, 15(4): 93-100. [in Polish + summary in English]

Zou G., Zhou L., Zhai G., Ding Y., Lu P., Liu, H., Zhen X., Liu X., Zhang L., Xin Z., Chen H., 2019. A high throughput method for screening deep-seeding tolerance in sorghum. Genetic Resources and Crop Evolution, 66(8): 1643-1651, doi: 10.1007/s10722-019-00835-0.

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