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REVIEW

Prospects for *Sorghum* cultivation in Poland

Roman Prażak*

Department of Genetics and Horticultural Plant Breeding, University of Life Sciences in Lublin, Akademicka 15, 20-950 Lublin, Poland

* Email: roman.prazak@up.lublin.pl

Abstract

The article presents the origin and cultivation history of sorghum (*Sorghum* spp.), its biology, requirements, cultivation techniques, and utilization. Sorghum is a cereal of the Poaceae. It is one of the most important crop plants grown in warmer parts of the world. Sorghum comes from Africa and therefore has very high heat requirements. In comparison with other crop plants, it is characterized by more efficient nutrient and water utilization. Sorghum grain is used to produce porridge, flour, syrup, sugar, ethanol, vegetable oil, starch, wax, paints, and animal fodder (the grain and entire plant). Sorghum straw is used to produce fibres, paper, and building materials. Sorghum has high energy value and can be an excellent source of renewable energy. It is easy to cultivate, with low soil and nutrient requirements. Due to its content of allelopathic compounds, it inhibits weed growth and has a phytosanitary effect. It is also resistant to disease and pests. It is a short-day plant, and in Polish climate conditions, it does not form sufficiently mature seeds, but produces a very high yield of green matter that can be used for fodder. Cultivation of sorghum during periodic water shortages may be an alternative solution for obtaining fodder when maize cultivation is unreliable.

Keywords

Sorghum spp.; plant biology; cultivation technology; utilization

Introduction

Observations of temperature conducted in Poland for many years confirm that the climate has warmed over the last century. It is possible that by the end of the century, climate change may increase the length of the growing season (the period during which the mean daily temperature does not fall below 5°C) by 50–60 days in eastern Poland and by over 100 days in western Poland (from 1960 to the end of the 1990s, the growing period increased by 10 days). As a consequence, all plants will be sown and harvested about 3–4 weeks earlier. The progressive warming of the climate in Poland may lead to an increase in the cultivation area of crops from warmer climate zones, such as sorghum or maize, characterized by C_4 photosynthesis. These plants are better adapted to higher temperatures. Sorghum is highly resistant to drought and requires high temperatures for proper growth and development [1–3]. It is grown in arid and semi-arid parts of the world and in places where conditions are unsuitable for maize [2–5]. In our country, sorghum can be grown as a forage crop intended for silage or for energy purposes, particularly in regions subjected to drought.

Origin and history of sorghum cultivation

The wild ancestor of sorghum was probably the African species *Sorghum arundinaceum*. This plant was first cultivated in 3000–5000 BCE in Ethiopia, Sudan, and Chad.

From Africa, sorghum reached the Near East, India, and China by trade routes. Paintings on the walls of the palace of Sennacherib, the king of Assyria, in Nineveh, reveal that sorghum was known in the eighth century BCE. In New Testament times, it was already widespread in Egypt and Palestine. It arrived in North America from Africa with slave transports. At the end of the nineteenth century, sorghum cultivation had become common in North America, and later in South America and Australia. Currently, sorghum is grown on a wide scale in the United States, Mexico, Brazil, Argentina, Australia, and China. It is also grown in parts of Europe, mainly in France and Italy. Sorghum ranks fifth in world cereal production, after wheat, rice, maize and barley [2,6–8].

Biological characteristics of sorghum

The sorghum species [*Sorghum bicolour* (L.) Moench] is in the class Liliopsida (monocotyledons), the subclass Liliidae, the order Poales, the family Poaceae (true grasses), the subfamily Panicoideae, the tribe Andropogoneae, and the genus *Sorghum* [9]. De Wet [10] recognized *S. bicolor*, representing all annual cultivated, wild and weedy sorghums along with two rhizomatous taxa, *S. halepense* and *S. propinquum*. *Sorghum bicolor* was further broken down into three subspecies: *S. bicolor* ssp. *bicolor*, *S. bicolor* ssp. *drummondii*, and *S. bicolor* ssp. *verticilliflorum*. Cultivated sorghums are classified as *S. bicolor* ssp. *bicolor* and are represented by agronomic types such as grain sorghum, sweet sorghum, sudangrass, and broomcorn [11].

Sorghum is a diploid species, similar to maize but without the cobs characteristic of maize. It is a spring annual. The root system is well developed and can penetrate from 1.5 to 2.5 m into the soil, so that the plant can take up water from its deeper layers. One of the advantages of sorghum is that it is highly resistant to lodging. The stalk is sturdy and straight with a groove on one side between the nodes. The thick stem reaches a length of up to 5 m. Sorghum stems are distinguished by a considerable carbohydrate fraction (cellulose and hemicellulose), while the leaf blades contain large amounts of protein. The leaf sheath surrounds the stem, and the leaf hangs down freely. The panicle may be loose or dense, reaching up to 50 cm in length. It contains small flowers grouped in spikelets and enclosed by glumes. There are male and female flowers on the panicle. Glumes vary in color from red or reddish brown to yellowish and are at least three-quarters as long as the elliptical grain. As seed matures, the panicle may droop. The color of the grain depends on the variety (predominately red or reddish brown), while the endosperm has no carotene and is white. The weight of 1000 grains is 14–28 g [12,13].

Cultivation of sorghum in Poland

In Poland, the sorghum cultivation area is small, at about 20 000 ha. As a short-day plant, in Polish conditions sorghum does not form sufficiently mature seeds, but it is able to produce a high yield of green matter, even up to 100 t ha^{-1}. In Polish, sorghum cultivation during water shortages can be an alternative solution making it possible to obtain fodder when maize cultivation is unreliable. Sorghum can be harvested many times per season, due to its rapid rate of regrowth, and replenish feed supplies [5,8,14,15].

Sorghum is a plant with unparalleled growth dynamics in our climate zone. It can supply feed in the middle of summer when the vegetation of most forage crops slows down. In Poland, sorghum is grown mainly for fodder, together with maize in a mixed cropping technique. A characteristic feature of sorghum is its relatively high yield potential. It is also distinguished by high dynamics of nutrient uptake and accumulation. In cases of severe lack of water, it can enter a state of dormancy, decreasing its growth rate, which can increase again when it begins to rain [13–16].

Climate and soil conditions for the cultivation of sorghum

Sorghum requires high temperatures for proper growth and development [3]. It tolerates drought well, but its yield is increased by suitable soil fertility and moisture. It is grown in arid and semi-arid parts of the world and in places where conditions are unsuitable for maize [5]. Sorghum is characterized by a C_4 carbon cycle, which enables efficient photosynthesis. C_3 plants of our climate zone are less tolerant of high temperatures than C_4 plants, whereas C_4 plants are more sensitive to cold. The optimum temperature for photosynthesis in C_3 plants is 10–25°C, while for C_4 plants it ranges from 30 to 40°C [17]. According to Still et al. [18], at temperatures above 24°C the yield of C_4 plants is many times greater than that of C_3 plants. Breeding work on earliness and tolerance for cold spring temperatures is carried out in order to adapt sorghum to Polish conditions [19]. During water shortages, sorghum takes up water from deeper layers of the soil. Sorghum plants are characterized by good water balance. Little water evaporates from the leaves and when the water shortage is severe the plants enter a state of dormancy [20,21].

Sorghum's soil requirements are low; it produces good yields on light and very light soils. It develops best on slightly acidic soils. Sorghum should not be grown on cold, heavy soils [13,22]. In a sorghum monoculture, soil fatigue occurs [4]. Sorghum is not considered very demanding. It is grown in places where climatic conditions are too dry and too hot for maize [22].

Sorghum is relatively easy to grow. It grows on both sandy soil and on heavy, clayey soils, at a pH range from 5.0 to 8.5. It is highly resistant to soil salinity and can also grow on soils with low permeability. For this reason, it is grown in extensive agricultural systems in Africa and Asia. It grows very well on light soils that warm up well and are fertile. It does not thrive in soils that are permanently wet and heavy, because it cannot tolerate stagnant water. Slow warming of the soil in the spring considerably reduces sprouting, and in the autumn poses the risk of damage to the plants by early frost. Sowing of sorghum on class V or even class VI soils can be successful. When sorghum is sown on very poor soils, precipitation is a limiting factor [13,14]. The water requirements of sorghum range from 400 to 600 mm, but it can also tolerate twice as much rainfall, i.e., 1200 mm. Its lower sensitivity to drought in comparison with other cereals is due to its greater efficiency in absorbing water from the soil, because it has twice as many secondary roots on each primary root. In a severe drought, the plants can enter a state of dormancy, decreasing their rate of growth, which can increase again when precipitation begins. It has adapted very well to maximally utilize solar radiation and heat. It is fairly intolerant of long-term flooding, but on the other hand, it does not respond to short-term water shortages with a decrease in yield. Among agricultural crops sorghum has by far the greatest heat requirements. They can be compared, for example, with those of tomatoes or cucumbers. Following emergence, if the spring is cold sorghum plants do not grow for a long time, and a slight frost can completely destroy them. The first frost in the autumn can also wither sorghum plants [5,8,11–13].

Sorghum production technology

In Poland, no varieties of sorghum are registered; varieties registered in other countries are grown. Two varieties of *Sorghum bicolor* are most often grown for fodder: 'Sucrosorgo 506' and 'Topsilo'. These varieties utilize water much more efficiently than maize and have exceptional growth dynamics in our climate zone [22]. It is worth mentioning that in the Czech Republic, new sorghum cultivar named 'Ruzrok' was registered in 2014 as a sorghum cultivar adapted to climatic conditions in the Czech Republic. The information on this Czech sorghum cultivar can be valuable for Polish farmers due to similar climatic conditions in the Czech Republic and Poland. The author of this cultivar is Ing. Jiří Hermuth, a sorghum breeder in Crop Research Institute in Prage-Ruzyně [23].

Tillage before sowing of this species is usually the same as for maize. Analysis of the differences between maize and sorghum in terms of heat requirements shows that sorghum in Poland is sown about 2–4 weeks later than maize [24]. Kruczek et al. [25] reported that sowing sorghum in III decade of May enlarged the plants density on 1 m^2 in comparison to the sowing about two weeks earlier.

The minimum soil temperature during sowing should be 10–12°C. Sorghum is sensitive to low temperatures. Damage due to cold can be seen even at 4°C. Hence the best time to sow this species is at the end of May and beginning of June, when the soil temperature is at least 12–14°C. Sorghum sown in the second third of May produces a 20.4% greater grain yield than sorghum sown in the last 10 days of April [24,26]. Sorghum emerges at a temperature of 15°C when sowing depth is 10 cm. Over-dense sowing increases green matter yield, but reduces dry matter and the digestibility of organic matter. This is due to a greater content of stems, and therefore fibre, in the organic matter. On the other hand, insufficiently dense sowing leads to tillering and an increased proportion of thick stems that are not easily digestible. The seeds are sown 5.5–6.7 cm apart in a row where density is planned at 200 000 – 240 000 seeds × ha^{-1} (about 6–8 kg ha^{-1}) and interrow width is 75–100 cm [13]. Reducing spacing of rows from 75 to 50 cm decreases grain yield by about 10% [27]. Szumiło et al. [28] and Sowiński and Szydełko [29] reported that increasing sowing density resulted in a gradual increase in the yield of green and dry weight, which resulted from increasing the number of shoots per unit area, and the number of generative organs.

Kruczek et al. [25] noted that enlarging the distance of rows from 30 to 90 cm limited the number of sorghum plants per area unit. The fresh and dry mass yields of whole plants of sorghum and stems, leaves and panicles increased in measure of enlarging the density of sowing from 15 to 25 seeds per 1 m^2 and in measure of reducing the distance between rows of plants from 90 to 30 cm. According to authors [25], the sowing term of sorghum did not influence fresh and dry mass yields of plants and their components.

Good forecrops for sorghum are non-cereals such as European yellow lupine, while cereals, except for oats, are unsuitable. Sorghum requires 30–60 kg ha^{-1} P_2O_5, 60–120 kg ha^{-1} K_2O, and 80–120 kg ha^{-1} N [13,22]. Reducing fertilizers in sorghum cultivation leads to decreased content of protein and sugars, while increasing the concentration of lignin in the leaf blade. The application of the increased doses of nitrogen fertilization in sorghum caused a greater accumulation of ashes. Content of carotene and chlorophyll pigments is reduced as well. Reducing fertilizer results in the absence of cyanogenic glycosides in sorghum stems [16,19]. Kruczek [30] reported that increasing doses of nitrogen enlarged the crude protein content and reduced the crude fibre content.

In organic farming, no mineral fertilizers are used, but only organic fertilizers. According to Księżak et al. [16,31] and Staniak et al. [32], organic fertilizer can be applied at a rate of 40 t ha^{-1}.

Sprouting is a crucial moment for sorghum. A lack of appropriate soil moisture during this period can delay emergence or dry out germinating plants. Therefore, particularly on light soils, it is recommended that seeds should be well pressed into the soil by compacting the soil with a roller [12,13].

Due to its late sowing, sorghum is well suited for cultivation after a winter cover crop, early vegetables, winter aftercrops, and even early potatoes. Harvesting of sorghum is fairly late (the end of September and October), which means that after sorghum only spring cereals can be sown [12,13].

Grown at wide row spacing, sorghum, which like maize has a slow initial growth rate, creates favorable conditions for the growth and development of weeds competing with it. During vegetation, mechanical weed control is performed in the interrows [31]. There are currently no herbicides registered for weed protection for sorghum [12,13].

Narrow row spacing of sorghum inhibits growth of weeds and of following crops. The allelopathic potential of sorghum is linked to the presence of both hydrophilic phenolic compounds, i.e., phenolic acids and their aldehyde derivatives leached from the aerial parts of the plants and exuded by the root system, and hydrophobic compounds, i.e., sorgoleone and its analogues, produced and exuded by specialized root hairs [4,7]. Sorgoleone inhibits or restricts the growth of mono- and dicotyledonous weeds [33,34], e.g., the dominant weed in maize cultivation – *Echinochloa crus-galli* [32,35]. Therefore, sorghum can be used in a crop rotation system as a forecrop or a companion crop. The phenomenon of allelopathy is increasingly finding application in agricultural practice due to its minimal negative impact on ecosystems and its low cost. Sorgoleone, due to its multi-faceted effects and well known mechanism of action on receiver plants, may have numerous applications. One of these is the potential for creating an effective herbicide [4]. In Polish climate conditions, sorghum has no natural pests, so it requires relatively few crop protection products. Aphids feeding on plantations may pose a certain threat. Diseases, on the other hand, are not a serious threat for sorghum [12].

Sorghum is harvested from mid-September to early October, which may depend on the earliness of the variety. Sorghum is harvested using machines designed for harvesting maize. A combine is suitable and no special attachments are necessary. In optimal conditions, humidity during grain harvest is 20% [5]. Sorghum is harvested during the waxy stage. The yield of fresh green matter of sorghum ranges from 44 to 85 t ha^{-1} depending on the year, the level of fertilization, the variety, and the region, and the dry matter yield ranges from 15 to 20 t ha^{-1} [36]. The nutritional value of the fresh matter of whole sorghum plants is about 70% that of maize [8]. Sowiński and Szydełko [28] reported that the chemical composition of the harvested fodder of sorghum-Sudangrass hybrid varied significantly depending on the method of cultivation. In twice-cut system, the yield of green matter was the highest, whereas more energy was obtained when the hybrid was once-cut. The higher yield of green mass resulted in higher content of mineral components. This resulted also in higher energy yield and total protein yield.

Utilization of sorghum

In tropical countries, sorghum can be grown for grain, while in Europe or Canada, due to the high production potential of green matter, it is grown for animal fodder. It is also used to make brooms. Sorghum grain is processed to produce porridge, flour, syrup, sugar, vegetable oil, and animal fodder (the grain and entire plant), and the straw is used as a building material. It is also used for production of bioethanol, paper, fibre, starch, wax, and paints. Due to its high content of soluble sugars, sorghum is an excellent raw material for silage [16,31]. Sorghum in the form of silage is used as fodder for cattle, and the grain as feed for pigs and poultry [14]. Sorghum contains antinutrient compounds such as tannins, which negatively affect its flavour, and cyanogenic glycosides, which generate prussic acid following decomposition. The content of these compounds has no significant effect on silage production because prussic acid has been shown to decompose in properly produced silage after three weeks. Content of these compounds is higher in young plants or damaged ones (including by cold) than in mature, healthy plants [15].

Sorghum can also be used for energy. Its energy value is 17.75 MJ kg^{-1} d.w. of stems, similar to that of maize – 17.79 MJ kg^{-1} d.w. of stems [37,38].

Conclusions

Sorghum can be recommended as a fodder crop and an energy crop. This is due to its low soil requirements, unparalleled growth dynamics in our climate zone, and abundant green matter yield. The yield, nutritional value and uptake of mineral nutrients depended mainly on the used method of cultivation [39]. Reducing spacing of rows decreases grain yield and increases the fresh and dry mass yields of whole plants of sorghum and stems. Increasing sowing density resulted in increase in the green and dry matter yield and energy accumulation. This resulted also in higher total protein yield. Increasing the number of cuts during vegetation season decreased the energy efficiency. In Poland, interest in biomass as the main source of renewable energy is continually growing. Fallow land and soil contaminated by industry and transport can be used for production of crops for energy purposes.

Moreover, sorghum can provide an alternative solution at poor sites, in periods of drought, and where maize cultivation has a high risk of failure, thereby securing supplies of bulk fodder for dairy and feedlot cattle. Breeding of new varieties that are better adapted to our climate conditions can contribute to more widespread cultivation of sorghum, as in the case of maize. Improvement is needed in such traits as cold tolerance, reduction of tannin content, fodder value, and especially adaptation to the light conditions prevailing in Poland.

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Perspektywy uprawy sorga w Polsce

Streszczenie

W artykule przedstawiono pochodzenie, historię uprawy sorga (*Sorghum* spp.), jego biologię, wymagania, agrotechnikę i wykorzystanie. Sorgo to roślina zbożowa z rodziny wiechlinowatych (Poaceae), jedna z najważniejszych roślin uprawnych, uprawiana w cieplejszych rejonach świata. Sorgo pochodzi z Afryki stąd ma bardzo duże wymagania cieplne. W porównaniu do innych roślin uprawnych charakteryzuje się wyższą efektywnością wykorzystania składników odżywczych i wody. Z ziarna sorga wytwarza się kaszę, mąkę, syrop sorgowy, cukier, bioetanol, olej roślinny, krochmal, wosk, farby, pasze. Słomę sorga również wykorzystuje się do produkcji pasz, poza tym włókien, papieru, oraz przeznacza na cele budowlane. Sorgo charakteryzuje się wysoką wartością energetyczną i może być doskonałym źródłem energii odnawialnej. Jest rośliną łatwą w uprawie, o małych wymaganiach glebowych i pokarmowych. Ze względu na zawartość związków allelopatycznych przyczynia się do zahamowania wzrostu chwastów i działa fitosanitarnie. Charakteryzuje się również odpornością na choroby i szkodniki. W warunkach polskiego klimatu sorgo, które jest rośliną dnia krótkiego, nie wytwarza dostatecznie dojrzałych nasion, ale za to daje bardzo wysoki plon zielonej masy z przeznaczeniem na paszę. Uprawa tej rośliny przy okresowych niedoborach wody, może być alternatywnym rozwiązaniem pozwalającym uzyskać paszę w przypadku, gdy uprawa kukurydzy jest zawodna.