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Economical Benefits of Sweet Sorghum (*Sorghum bicolor* L.) Products

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Abstract: Sweet sorghum (*Sorghum bicolor* L), which later can be divided into grain sorghum and sweet stalk sorghum are highly water efficient crop that requires low amount of water intake for its biomass growth and grain production. Stalk of sweet sorghum produce juice that has high sugar content, which can be used as a main source of ethanol production, whereas grain of sorghum can also be used as raw materials for food, feed and functional food. The quality feature of sorghum that suitable to be use for bioethanol production is determined by its high sugar content in stalk or the amount of carbohydrate in grain. Whereas the protein content in grain and lignocellulosic in the stalk is an added value. Among many parts of sorghum plant, the stalk gives highest contribution to produce juice as raw material for bioethanol. Ethanol production was determined by the production of biomass and sugar content of the stalk. Stalk biomass; brix level in stalk juice had high correlation to sweet sorghum ethanol production.The primary sugars present in grain of sweet sorghum are fructose, glucose, raffinose, sucrose and maltose. In sorghum leaves, sucrose is translocated and transformed into starch during the development of grains. Grain plus stem of sweet sorghum has been shown to yield more fermentable carbohydrates than other fuel crops. In addition, the grain can be used for production of high fructose syrup and animal feed. Therefore, sorghum is an excellent crop for biomass production. The high nonstructural carbohydrate content of its vegetative biomass can be fermented to methane or ethanol. Sugar production of sweet sorghum was compared with sugarcane and sugar beet and the results showed that sugar production from sweet sorghum is cheaper than both sugarcane and sugar beet. The emerging enzymatic hydrolysis technology has not been proven on a commercial scale. One ton of corn grain produces 387 L of 182 proof alcohol while the same amount of sorghum grain produces 372 L. Sorghum is used extensively for alcohol production (, where it is significantly lower in price than corn or wheat. The commercial technology required to ferment sweet sorghum biomass into alcohol has been reported in China. One ton of sweet sorghum stalks has the potential to yield 74L of 200- proof alcohol .Since Iran has dry and hot climatic conditions therefore sweet sorghum has emerged as a leading candidate for liquid sugar and biofuel production with minimum inputs .Sweet sorghum can accumulate juice up to 78% of the total biomass, whereas the Brix content of sweet sorghum has been estimated to range from 14 to 23%. The sugars in sweet sorghum stalks mainly comprise sucrose (~75%) with some amount (~2.6%) of fructose and glucose. Ethanol produced from sweet sorghum is safer for environment due to low sulfur content, low biological and chemical oxygen demand and high octane rating. During concentration of juice to syrup, the foam and froth produced can be processed and used to feed livestock or as an organic fertilizer. After juice extraction, the fibrous leftover material, known as bagasse, serves as a raw material for handmade paper, electricity generation, and bio-composting. Sweet sorghum is being widely considered to be suitable biofuel feedstock to a tropical country like India as sugarcane is grown primarily for sugar while corn is used in food and poultry industry. No significant changes in pH value, sugar contents, and sugar profiles were observed in juices stored in a refrigerator. The whole sweet sorghum plant used as feed stock for bioethanol production and concluded that both juice extracted from the stem and residual bagasse can be used for fermentation to ethanol. There was a significant difference in the sugar content of the samples extracted in different ways; samples extracted without the leaves showed approximately 20% higher sugar content. This crop has also been included in the list of the best sources of liquid biofuels in terms of the development of renewable energy in China. A large amount of biomass by-products are left after the use of sweet sorghum stalks for juice can be utilized in a number of possible ways: biogas production, soil fertilizers or production of pellets and briquettes for burning. Additionally, both sorghum bagasse and molasses can be potentially used for biobutanol production.

Keywords: *Sorghum bicolor* L, ethanol, Economical Benefits.

INTRODUCTION

In Indonesia especially, production of ethanol mainly utilize sugarcane molasses and maize kernel as its raw materials. And the demand from the consumer to use ethanol as the new source of renewable energy grows rapidly more than the supply can fulfill (Kennedy and Turner, 2004). Consequently, with the increasing of demand, ethanol production will be utilizing more toward sustainable raw materials that do not compete with major commodities such as food crop both in term of land use and supply of materials. It is also important not to risk national food security in deciding which crop that is suitable as a source of ethanol. Sweet sorghum has increasingly been used to produce free-fermentation sugar, which could potentially derive to substitute fuel oil, food, feed and various other products (Chiaramonti. *et al*., 2004). Because of these advantages, sorghum is the crop that has promising feature as a source of biofuel, food and feed.

The function of sweet stalk sorghum is equal to what sugarcane offer, because it contains high sugar content which can produce ethanol through fermentation process (FAO, 2002).

Sweet sorghum (*Sorghum bicolor* [L.] Moench), which later can be divided into grain sorghum and sweet stalk sorghum are highly water efficient crop that requires low amount of water intake for its biomass growth and grain production. It can be cultivated on marginal land, mainly drought prone areas where other crops cannot survive (McLaren. *et al*., 2003). The morphology of sweet sorghum is relatively different from grain sorghum, which is

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generally have taller plant height and possess high biomass (Turhollow. *et al*., 2010).

Furthermore, stalk of sweet sorghum produce juice that has high sugar content, which can be use as a main source of ethanol production (Reddy and Yang, 2005), whereas grain of sorghum can also be used as raw materials for food, feed and functional food (Sumaryono, 2006).

Factors affecting biomass and juice yield are genetic of the varieties and the environment of the cultivation areas. Sweet stalk sorghum have higher biomass than grain sorghum, however yield of biomass also depend on the precipitation rate during anthesis and drought stage (Maw. *et al*., 2016). Another factor that can influence sweet sorghum is growing season, where longer growing season in temperate climate can affect and improve biomass and stalk juice yield (Houx and Fritschi, 2013).

Beside genetic, factor that likely affects level of brix content is water consumption which can either be by rain precipitation of by irrigation during cultivation (Tamang. *et al*., 2011).

The quality feature of sorghum that suitable to be use for bioethanol production is determined by its high sugar content in stalk or the amount of carbohydrate in grain. Whereas the protein content in grain and lignocellulosic in the stalk is an added value (Yudiarto, 2006). Among many parts of sorghum plant, the stalk gives highest contribution to produce juice as raw material for bioethanol (Almodares and Hadi, 2009).

Another study carried out by Singgih (2006) and Pabendon. *et al*., (2012) stated that ethanol production was determined by the production of biomass and sugar content of the stalk.

Furthermore, Pabendon. *et al*., (2013) also reported that stalk biomass; brix level in stalk juice had high correlation to sweet sorghum ethanol production. Sorghum plant is sensitive to photoperiodism or relative length of day and night. Sorghum requires at least 12 hours triggering the internal mechanism that initiate growth, reproduction, flowering and seed development (Qingshan and Dahlberg, 2001).

Bennet and Anex (2008) stated that juice production from sweet sorghum that is sustainable can be performed by on-farm method. Another advantage of cultivating sorghum is its ability to grow new shoot (ratoon) from previously harvested stalk, and the shoot will grow into new plant that can be harvested for the second time (Livingston and Coffman, 2003). According to Tsuchihashi and Goto (2004), sorghum plant can be harvested twice or third times which include primer plant and its ratoon. Therefore, it can supply the demand for raw materials for carbohydrate, green fodder or bioethanol in sustainable ways. Study of ratoon ability performed by Effendi. *et al*., (2013) In rainy season on several sorghum genotypes showed that Super-2 and Super^{-1} had low ratoon ability, with ratoon percentage at 33-44 % and also low brix percentage in stalk (9 %).

The period time of fermentation roughly 14–21 days by adding only bread yeast (Saccharomyces cerevisiae). The amount of ethanol produced was highly related and affected by the method being used to ferment stalk juice (Asli, 2010; Liu and Shen, 2008; Sipos. *et al*., 2010 and].

Considerable progress has been made in breeding for improved sweetsorghum lines with higher millable cane and juice yields in India. A few of these cultivars have been released, e.g., SSV 84, SSV 74 and NSSH 104 (Reddy et al . 2005).

There are many crops available for producing energy such as sweet sorghum which not only produce food, but also energy (Reddy et al., 2005), feed (Fazaeli *et al*., 2006) and fiber (Murray *et al*., 2008a,b). Sorghum can be classified as sweet, grain and forage types (Almodares *et al*., 2008b). Sweet sorghum like grain sorghum produces grain 3 -7 tha^{-1} (Almodares and Mostafafi, 2006). But the essence of sweet sorghum is not from its seed, but from its stalk, which contains high sugar content (Almodares. *et al*., 2008c). In general, it can produce stalk 54 - 69 tha^{-1} (Almodares. *et al*., 2008c).

Besides having rapid growth, high sugar accumulation and biomass production potential, sweet sorghum has wider adaptability (Reddy. *et al*., 2005). Sweet sorghum has many good characteristics such as a drought resistance (Tesso *et al*., 2005), water lodging tolerance, salinity resistance (Almodares *et al*., 2007a; Almodares *et al*., 2008) and with a high yield of biomass etc.

Thus development of sweet sorghum will play an important role in promoting the development of agricultural production, livestock husbandry (Fazaeli *et al*., 2006).

In addition, the produced baggas after juice extraction can be used for ethanol production or animal feed (Jafarinia *et al*., 2005). However, presently it is not economically feasible to produce ethanol from sweet sorghum baggas (Drapcho *et al*., 2008).

It is a short –day plant (Almodares *et al*., 2000; Rezaie *et al*., 2005), and most varieties require fairly high temperature (Reisi and Almodares, 2008) to make their best growth. The cereals (Tesso *et al*., 2005) and tolerate a wide range of soil conditions (Almodares *et al*., 2008e). Sorghum tolerates compacted subsoil and can stand high press wheel pressure at planting. It tolerates a pH range of 5.0 to 8.5 (Smith and Frederiksen, 2000) and some degree of salinity (Almodares *et al*., 2007a, 2008a, 2008c, 2008), alkalinity and poor drainage (Almodares et al., 2008e). It also will grow on heavy, deep cracking vertisols and light sands (Smith and Frederiksen, 2000). The seed of sweet sorghum should be planted deep enough to give it moisture to germinate and allow its roots to grow down through moist soil into subsoil moisture, ahead of the drying front (Almodares *et al*., 2008e).

Planting time (Almodares and Mostafafi, 2006) usually start when the air temperature is above 12° C (Almodares *et al*., 2008e).

Also, it may cause late and troublesome harvest and may expose the crop to pests and diseases and other hazards which are dominant at the end of the crop season (Almodares. *et al*., 2008e). Balanced fertilization can increase yield (Rego. *et al*., 2003).

Nitrogen fertilizer and its application time promotes sucrose content and growth rate in sweet sorghum (Tsialtas and Maslaris, 2005). Application of adequate amounts of K fertilizer increase yield responses than increasing levels of nitrogen fertilizer alone (Pholsen and Sornsungnoen, 2004; Almodares and Mostafafi, 2006; Almodares. *et al*., 2006; Almodares. *et al*., 2008d; Fazaeli. *et al*., 2006) Sweet sorghum is harvested at milk stage (Ranjbar and Almodares, 2002; Almodares . *et al*., 2007b).

The primary sugars present in grain of sweet sorghum are fructose, glucose, raffinose, sucrose and maltose. In sorghum leaves, sucrose is translocated and transformed into starch during the development of grains (Smith and Frederiksen, 2000).

Grain plus stem of sweet sorghum has been shown to yield more fermentable carbohydrates than other fuel crops (Murray. *et al*., 2008b).

In addition, the grain can be used for production of high fructose syrup and animal feed (Hosseini . *et al*., 2003). Therefore, sorghum is an excellent crop for biomass production.

The high nonstructural carbohydrate content of its vegetative biomass can be fermented to methane or ethanol (Reddy. *et al*., 2005). Ethanol production by fermentation of sugar solutions obtained from sweet sorghum varies widely among years at different locations, fertility (Almodares . *et al*., 2006, 2008d), moisture, planting/harvest dates (Almodares and Mostafafi, 2006), preclude a strict linear association between number of frost free days (Almodares . *et al*., 2007b).

Sorghum nonstructural carbohydrates contents are affected by temperature, time of day (Almodares . *et al*., 2000), maturity , cultivar, culm section, spacing and fertilization (Almodares . *et al*., 2008d).

In the sweet sorghum, sucrose, glucose and fructose contents increase after anthesis (Almodares et al., 2008c). In stems, non-structural carbohydrates contents increase after preboot and reach a maximum level near post anthesis (Almodares. *et al*., 2008c).

Sugar production of sweet sorghum was compared with sugarcane and sugar beet and the results showed that sugar production from sweet sorghum is cheaper than both sugarcane and sugar beet (Blas . *et al*., 2000).

Presently, ethanol as an oxygenous biomass fuel is considered as a predominant alternative to MTBE for its biodegradable, low toxicity, persistence and regenerative characteristic (Cassada . *et al*., 2000).

Ethanol may be produced from many high energy crops such as sweet sorghum , corn, wheat, barley, sugar cane, sugar beet, cassava, sweet potato and etc (Drapcho. *et al*., 2008).

The emerging enzymatic hydrolysis technology has not been proven on a commercial scale (Taherzadeh and Karimi, 2008). One ton of corn grain produces 387 L of 182 proof alcohol while the same amount of sorghum grain produces 372 L (Smith and Frederiksen, 2000).

Sorghum is used extensively for alcohol production (Smith and Frederiksen, 2000; Gnansounou. *et al*., 2005), where it is significantly lower in price than corn or wheat (Smith and Frederiksen, 2000). The commercial technology required to ferment sweet sorghum biomass into alcohol has been reported in china (Gnansounou . *et al*., 2005). One ton of sweet sorghum stalks has the potential to yield 74 L of 200- proof alcohol (Smith and Frederiksen, 2000).

Juice is extracted by series of mills (Almodares. *et al*., 2008e). The juice coming out of milling section is first screened, sterilized by heating up to 100° C and then clarified (Quintero. *et al*., 2008).

Since Iran has dry and hot climatic conditions (Almodares, 2000) therefore sweet sorghum has emerged as a leading candidate for liquid sugar and biofuel production with minimum inputs .

Because, sweet sorghum has higher tolerance to drought (Tesso . *et al*., 2005), water logging and salt (Almodares et al., 2008, 2008a), alkali and aluminum soils.

Energy sorghum is specifically bred for high lignocellulosic biomass that can be converted to biofuels, whereas sweet sorghum, also known as sweet stalk sorghum, refers specifically to genotypes that accumulate soluble sugars in the stalk (Codesido. *et al*., 2013). Sweet sorghum may grow up to twenty feet tall and produce significantly higher biomass yields compared to grain sorghum. Stems of sweet sorghum are thicker and feshier than the grain varieties, though the seed yield is relatively low (Whitfeld. *et al*., 2012). Sweet sorghum can accumulate juice up to 78% of the total bio-mass, whereas the Brix content of sweet sorghum has been estimated to range from 14 to 23% (Vinutha. *et al*., 2014). The sugars in sweet sorghum stalks mainly comprise sucrose (~75%) with some amount (~2.6%) of fructose and glucose (Kawahigashi. *et al*., 2013). In comparison to lignocellulosic biomass crops like switchgrass and Miscanthus, soluble sugars in the form of glucose, fructose, and sucrose in sweet sorghum are readily fermentable (Regassa and Wortmann, 2014).

According to U.S. Department of Agriculture, the ratio of energy invested to energy obtained during biofuel extraction from sweet sorghum is estimated as 1:8 (Billings, 2015), which may further be improved using engineering and molecular breeding technologies.

Ethanol produced from sweet sorghum is safer for environment due to low sulfur content, low biological and chemical oxygen demand and high octane rating (Reddy. *et al*., 2006).

Although, annual ethanol output from sweet sorghum depends on several factors including genetic background, time of the year, soil quality, and other environmental factors, sweet sorghum crop is estimated to produce up to 8000 l/ha/year of ethanol (Reddy. *et al*., 2006).

During concentration of juice to syrup, the foam and froth produced can be processed and used to feed live-stock or as an organic fertilizer (Reddy. *et al*., 2006). After juice extraction, the fibrous leftover material, known as bagasse, serves as a raw material for handmade paper, electricity generation, and bio-composting (Rao. *et al*., 2012). Te sweet sorghum germplasm exhibits trade of between sugar content and biomass yields with some genotypes containing high sugar content with lower biomass, while others usually with lower sugar yields have high stalk biomass (Disasa. *et al*., 2016). Sweet sorghum is an annual plant with a short life cycle of about 4 months. It allows two crops per year though optimal planting date varies with the place of cultivation and the variety (Vermerris. *et al*., 2008). It is a warm-season crop with the highest productivity in rainy and summer seasons. Sweet sorghum is mainly adapted to arid and semi-arid regions, with temperature range of 12–37°C, optimum range being 32–34°C (Rao. *et al*., 2009. Although increased seeding rate com-promises the size of individual plants and total yields, it has positive impact on the total biomass and sugar yields (Rao. *et al*., 2013 and Han. *et al*., 2012). Tillage and use of fertilizers can also significantly affect the total yields. Pittelkow and colleagues evaluated several environmental and agronomic factors on no-till yields (Snider. *et al*., 2012). Teir results showed that under water limiting conditions, no-till system increases overall yield as compared to conventional tillage systems in arid regions. It has also been reported that sweet sorghum requires ~36% of nitrogen fertilizer that is needed for similar ethanol yields from corn (Pittelkow. *et al*., 2015).However, the use of moderate amount of nitrogen fertilizers enhances sweet sorghum growth rate and ethanol yields (Olugbemi. *et al*., 2016). Although moisture availability is critical for the plant growth, sweet sorghum is relatively drought-tolerant and can be adapted to grow on marginal lands with low water availability (Marta. *et al*., 2014 and Olukoya. *et al*., 2016). Te well-developed root structure that can extend up to 2 m below ground aids to obtain moisture from the soil. Under adverse conditions or in the absence of sufficient moisture, sweet sorghum plants become dormant but can resume growth as soon as favorable conditions are available, whereas excessive moisture usually results in reduction of overall biomass as well as quality and yield of stalk juice (Mocoeur Kumar However, stage of maximum sugar accumulation varies in different varieties with some genotypes mainly accumulating sugars between dough stage and physiological maturity, whereas others accumulate sugars up to 15 days post-physiological maturity (Kumar. *et al*., 2011). Oyier and coworkers evaluated four sweet sorghum genotypes to study the effect of harvesting stage on bioethanol production and suggested 104–117 days after planting as appropriate time for harvesting sweet sorghum canes [Oyier. *et al*., 2017). Sorghum bicolor (L.) Moench is a member of Andropogoneae tribe of subgroup panicoideae of the grass family, poaceae (Kellogg, 2013).

Te subgenus Sorghumcontains three species includ-ing S. bicolor, S. propinquum, and S. halepense. Further, S. bicolorhas three subspecies including S. bicolor, S. bicolor drummondii, and S. bicolor verticilliforum(for-merly referred as arundinaceum) (Wiersema and Dahlberg, 2007).

How-ever, later studies showed clustering of sweet sorghum lines with other S. bicolor genotypes suggesting that sweet sorghum has a polyphyletic origin and therefore, apart from race bicolor, may have parentage from other previously mentioned races as well (Ritter. *et al*., 2007). In Africa, where most of the wild germplasm has originated, intermediate varieties are also common. For instance, there are many durra-bicolor intermediates in Ethiopian highlands (Mekbib, 2009).

In United States, sweet sorghum was introduced in the form of Chinese Amber (from china), Orange, Sumac/Redtop, Gooseneck/Texas Seeded Ribbon Cane, Honey and White African (from China and Africa via France) (Murray. *et al*., 2009). A collection of 2180 accessions of sweet sor-ghum in the US National Plant Germplasm System has served as a source of germplasm for developing varie-ties in the Mediterranean region and Latin America (Cuevas. *et al*., 2014).

Sweet sorghum is being widely considered to be suitable biofuel feedstock to a tropical country like India as sugarcane is grown primarily for sugar while corn is used in food and poultry industry (Zhang. *et al*., 2010).

Some sweet sorghum lines attain juice yields of 78 % of total plant biomass, containing 15 to 23% soluble fermentable sugar (Srinivasarao. *et al*., 2009). It can produce very high yields with irrigation. During very dry periods, sweet sorghum can go into dormancy, with growth resuming when sufficient moisture levels return (Gnansounou. *et al.*, 2005).

The high WUE and low N requirements of sorghum also provide significant advantages to the growers, because sorghum fits into a normal rotation scheme with corn and soybeans, yet has lower production costs and employs similar production equipment (Srinivasarao. *et al*., 2011). Its ratooning ability enables multiple harvests per season, a feature that could expand the geographical range of sorghum cultivation. For example, in Nebraska, cold-tolerant sweet sorghum planted in April yielded 22 t ha^{-1} of dry biomass, and a ratoon crop harvested from the same material in mid-October gave an additional 12 t ha^{-1} (Ali. *et al*. 2008). The grain stalk juice and bagasse (the fibrous residue that remains after juice extraction) can be used to produce food, fodder, ethanol and power.

Further the lignocellulosic ethanol realization from sweet sorghum is relatively higher vis avis other types of sorghums (Dien. *et al*., 2009).

On the other hand, both sweet sorghum hybrids and varieties had higher stalk sugar yields (50% and 89%) and lower grain yields (25% and 2%) in the post-rainy season (Reddy. *et al*., 2012). Thus, there is little tradeoff between grain and stalk sugar yields in the sweet sorghum hybrids in the rainy season while the tradeoff is less in varieties in the post-rainy season (SrinivasaRao. *et al*., 2009 and 2010; Ganesh. *et al*., 2010).

This is further supported by other published work (Zhao. *et al*., 2009) showing that there is significant soluble sugars content in the stems (79-94%) during post-anthesis period, with the hybrids exhibiting significantly high soluble sugar content over varieties with same maturity period, effects of year, harvest time and genotype on calculated ethanol yield (CEY) are highly significant.

Conventional breeding approaches are practiced for an increase in sucrose yield; R lines showed a Brix% of 12 to 24% in the rainy season and 9 to 19% in the post rainy season. 600 A/B pairs were screened at ICRISAT and the % brix ranged from 10 to 15% in the rainy season and 8 to 13% in the post rainy season. (Srinivasarao. *et al*, 2009) The bagasse of sweet sorghum is highly palatable and intake by livestock is more vis avis normal sorghum stover (Blummel. *et al*., 2009, Srinivasarao. *et al*., 2012b).

Sweet sorghum for biofuel production in hot and dry countries to solve problems such as increasing the octane of gasoline and to reduce greenhouse gases and gasoline imports (Almodares and Hadi, 2009).

No significant changes in pH value, sugar contents, and sugar profiles were observed in juices stored in a refrigerator (Wu Xiaorong. *et al*., 2010).

Jianliang. *et al*. reported the ethanol production from sweet sorghum juice by immobilized yeast in optimized media conditions (Jianliang. *et al*., 2009).

In a study by Sipos Balint. *et al*. (2009), they used the whole sweet sorghum plant as feed stock for bioethanol production and concluded that both juice extracted from the stem and residual bagasse can be used for fermentation to ethanol.

There was a significant difference in the sugar content of the samples extracted in different ways; samples extracted without the leaves showed approximately 20% higher sugar content (Ba´lint Sipos. *et al*., 2009).
Freshly extracted juice sterilized by heating up to 100°C and then clarified (Quintero. *et al*.2008). The ethanol production from sweet sorghum grain is similar to corn and it can be described according to Quintero. *et al*. (2008).

Thus, there is little tradeoff between grain and stalk sugar yields in the sweet sorghum hybrids in the rainy season, while the trade off is less in varieties in the post-rainy season (Kumar. *et al*., 2010). The crop, even if uptakes different amount of nitrogen, seems to be insensitive to the mineral nitrogen supply and also seems to have a great potentiality in semi-arid environment in terms of yield production (Cosentino. *et al*., 2012).

Besides the high amount of sugar in its juice, sorghum showcases a high productivity of grain, which is rich in starch. Raw biomass of this crop or bagasse has been used recently as a promising feedstock for biogas production (Mossi. *et al*., 2018; Draghici. *et al*., 2019 and Mago, 2010). Thus, bioethanol from Sorghumcan be produced at a conventional alcohol production plant (Tsygankov. *et al*., 2013).

This crop has also been included in the list of the best sources of liquid biofuels in terms of the development of renewable energy in China (Liu. *et al*., 2015).The biomass of sweet sorghum is similar to corn in terms of chemical composition, but its yield is much higher and usually reaches up to 40-80 t/ha. Sorghum stems (stalks) comprise over 75% of the biomass yield. Sweet sorghum also produces grain, which is rich in starch (68-73%) and protein (11-15%) (Rakhmetov, 2011; 2018; Blume. *et al*., 2014; Volod'ko. *et al*., 2012 and Rakhmetov. *et al*., 2018).

Mahmood. *et al*., (2013) reported similar maximum content of sugar in the juice of sorghum hybrids up to 24.3%.

A large amount of biomass by-products are left after the use of sweet sorghum stalks for juice pressing and further ethanol production. Bagasse can be utilized in a number of possible ways: biogas production (Kulichkova. *et al*., 2020), soil fertilizers or production of pellets and briquettes for burning (Stamenkovic. *et al*., 2020), etc.

Additionally, both sorghum bagasse and molasses can be potentially used for biobutanol production (Tigunova. *et al*., 2013).

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