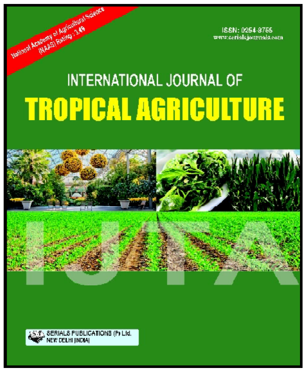

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Sweet Sorghum: An Alternative Source of Food, Feed, Sugar and Bio-fuel (A Review)

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INTRODUCTION

Sorghum (*Sorghum bicolor* L. (Moench)), is multipurpose known cereal, contains grain, forage and sweet types. Sweet sorghum mainly is planted for sugar and ethanol production (Gnansounoua *et al.,* 2005). Sugar beet and sugarcane are the main source of sugar production in the world (Pennington and Baker, 1990). Sweet sorghum is well adapted to sub-tropical (Rego *et al.*, 2003) and temperate regions of the world. Also, Sorghum is genetically accustomed to hot and dry conditions, but by Smith *et al.* (1987) it has been reported that, it can be cultivated worldwide in temperate climates also. Cowley and Smith (1972), Ferraris and Stewart (1979), and Inman-Bamber (1980), had shown that sweet sorghum is a potential source of sugar and a multipurpose industrial crop. As Ferraris and Stewart (1979) reported, sweet sorghum can be processed for sugar and its components can be used for many other products. It has high biomass production, low water requirement (Girma, 1989; Mastroilli *et al.,* 1999) and short growing season (Roman *et al.,*1998). Therefore, sweet sorghum can substitute sugar beet and sugarcane under hot and dry climate conditions (Kulkarni *et al.*, 1995). Sweet sorghum can be made as a special purpose sorghum with a sugar-rich stalk, almost like sugarcane. Besides having rapid growth, high sugar accumulation, and high potential biomass, sweet sorghum has wider adaptability (Reddy and Sanjana 2003)to various climatic zones. Irrigational water availability is poised to become a major constraint to agricultural production in coming years (Ryan and Spencer 2001); owing to this cultivation of sugarcane becomes difficult. Sweet sorghum can be grown with less irrigation and rainfall and required inputs compared to sugarcane. The sugar content in the juice extracted from sweet sorghum varies from 16–23% Brix. So it has a great potential for the preparation of jaggery, syrup and most importantly fuel- alcohol production (Ratnavathi *et al.* 2004a). The syrup, obtained from the sweet sorghum, by its contents of biologically active substances and micro elements, is like a natural honey. As a result of the investigations on physico-chemical characteristics and sanitary estimates of sweet products obtained from sweet sorghum, a wide spectrum of their utilization in food industry, medicine and animal feeding was found encouraging (Morris *et al.,* 1997; Rajvanshi, and Nimbkar, 2001). The stillage after extraction of juice from sweet sorghum can be used for generation ofadditional power. In addition to being highly productive in terms of biomass, sweet sorghum is also known to show drought and water logging resistance and salinity tolerance. For these reasons, among the biomass energy crops, it is considered as the 'camel' crop (Li, 1997).

Variations in the quality parameters of sweet sorghum across different dates of sowing and spacing on stem yield

For sugar yield that correlates with the ethanol yield, July and August sowings were superior to the subsequent sowings in September to December. However, for Brix value, July, August, September and November sowings were similar, while October sowings had significantly lowered the yield and December sowings had significantly higher Brix (Belum *et al.,* 2007). When hybrids and normal varieties were observed as two separate groups,normal varieties have performed better than hybrids for sugar yield (Belum *et al.*, 2007). Hybrids have better buffering capacity to the environmental fluctuations compared to normal varieties (Belum *et al.,* 2007). According to Hipp *et al.* (1969) yields of sweet sorghum stalks increased with early planting, but brix value, sucrose content and juice purity were not affected by planting date. Similarly, Cowley and Smith (1972) reported slow decline of yields with late planting but did not find any correlation between planting dates, sucrose content, purity and brix value. Maheshwari *et al.* (1974), reported a decline in yield of sweet sorghum stalks but juice quality like sucrose content, juice purity and brix value were improved with the delay in planting dates. Inman- Bamber (1980) reported a rapid decline in the stalk and sucrose yield of sweet sorghum with delayed planting dates. Similarly, Ferraris and Charles- Edward (1986), Petrini *et al.* (1993) and Almodares *et al.* (1994), reported higher yields of stalks, brix value, sucrose content and juice purity with the early planting dates than the late planting. Under most field conditions late planting is associated with a reduction in number of days to panicle initiation and flowering, which might be due to the effect of temperature and photoperiod (Pauli, Stickler and Lawless, 1964; Hesker 1966; Caddel and Weibel, 1971). Stickler, Pauli, Laude, Wilkins and Mingis (1961), showed that early planting in grain sorghum increased grain yields through enhanced tillering and number of heads per unit area. Planting time (Almodares and Mostafafi, 2006), usually starts when the air temperature , above 12° C (Almodares *et al.*, 2008e). Late planting reduces the length of the growing season; yield and carbohydrate content (Almodares *et al.,* 1994a). Also, it may result in 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). The seeds of sweet sorghum should be planted deep enough to receive the 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).

Effect of Nitrogen treatments, cultivars and harvest stages on stalk yield and sugar content in Sweet Sorghum

Sorghum is a C_4 crop and have good N use efficiency (Gardner *et al*.,1994). Application of nitrogenous fertilizers increases sweet sorghum stalk yield (Jihnston, 2000). Gardner *et al.* (1994), reported nitrogen fertilizers increases sugar content, protein percent and growth rate in case of sweet sorghum. Application of nitrogen fertilizers is mostly increases brix value (Pholsen and Sornsungnoen, 2004). Galani *et al.* (1991) reported that an increase in juice yield and no response in juice brix resulted in an experiment with increasing N rates. Cowley and Smith (1972), did not find any correlation between Nitrogen levels and sucrose content and purity. Timing of Nitrogen application might have also detrimental effects on juice quality. Freeman et al. (1973), reported that late application of fertilizers, especially Nitrogen, should be avoided as this interferes with juice quality. Quality and quantity of sugar in stem or stalk changes at different growth stages; so harvesting stage is an important factor for sugar content (Parvatikar and Manjunath,1991). Also sweet sorghum accumulates large amounts of sugar in its stems near the time of grain maturity. Sweet sorghum has 10 to 25% sugar in stalk juice, with sucrose being the predominant disaccharide (hunter and Anderson, 1997). Nitrogen increases stalk yield and sugar content in sweet sorghum (Leible and Kahnt, 1991; Sumantri and Lestari, 1997). Therefore, this was designed to determine the optimum Nitrogen treatment, cultivars and harvesting stages of sweet sorghum for obtaining highest stalk yield, sucrose content and Brix value under different climatic conditions. To improve yield and quality of sorghum fodder it is essential to determine its nitrogen requirement. The application of nitrogen not only affects the yield but also improves quality of its protein contents (Mohamed and hamed, 1988). According to Patel *et al.* (1994), dry matter accumulation was increased and crude fiber contents were decreased with the increased Nitrogen applications accordingly. Increased Nitrogen rates increased the protein and digestibility of dry matter yield to the animals (Rana *et al.*1990). The varieties vary greatly in their response to fertilizers application (Chandravanshi *et al.,* 1973).

Another important factor affecting the quality and yield of forage crops is the growth stage during the time of harvest. The effects of harvesting dates on the chemical composition of forage are greater than that of cultivars (Firdous *et al.*, 1996). Rana *et al.* (1990) reported that sorghum generally harvested after the 90 days of sowing observed increased in the yield of the first cut but showed decrease in the second cut forage yield. Total yield was lowest, when the first cut was taken after the 60 days of sowing. The crop harvested at 75 days after sowing gave the maximum plant height and minimum plant height was obtained when the crop was nearly harvested at 45 days after sowing. An increase in the plant height was also observed when harvesting somewhat delayed has also been reported by Musa *et al.* (1993). An increase in the stem diameter with Nitrogen application has also been reported by Ahmed (1999) and Ali (2000). Ahmed (1999) and Ali (2000), have also reported significant effect on Nitrogen application on green fodder yield of sorghum. But, Chittapur *et al.* (1994) reported non-significant effect of Nitrogen application on fodder yield of sorghum. These contradictory results might have been due to variation in fertility status of soil, climatic conditions or genetic traits of crop plants. Increase in fodder yield by extending period before the harvesting has been also reported by Balasubramanian and Rananoorthy (1996). The significant effect of Nitrogen levels on dry matter yield has also been reported by Ahmed (1999) and Ali (2000). The maximum and minimum crude protein contents were obtained when crop was harvested at 45 and 75 days after sowing respectively (Muhammad *et al.*, 2002). The results are quite in line with those of Ahmed (1999) and Ali (2000). Neutral detergent fiber contents were increased with advancement in maturity. The maximum and minimum neutral detergents- fiber contents were recorded when crop was harvested at 45 and 75 days after sowing, respectively (Muhammad *et al.*, 2002). Lemerle *et al.* (1985) also reported an increase in neutral detergent fiber with delayed harvesting. Delayed in fat content with delayed harvesting has also been reported by Bajwa *et al.* (1983).

Sugars in Sweet Sorghum

Sweet sorghum like grain sorghum produces grains approximately in between 3 to 7 t/ha (Almodares and Mostafafi, 2006). But the essence of sweet sorghum is not from its seeds, but from its stalk, which generally contains of high sugar content (Almodares *et al.*, 2008c). In general, sweet sorghum can produce stalk yield of 54 to 69 t/ha (Almodares *et al.*, 2008c). The sugar content in the juice of sweet sorghum reported varies in different varieties (Almodares *et al.*, 1994a). The Brix range also varies in different varieties of sweet sorghum which ranges from 14.32 to 22.85 % (Almodares and Sepahi, 1996). Besides having rapid growth, high sugar accumulation (Almodares and Sepahi, 1996), and biomass production potential (Almodares *et al.*, 1994a), sweet sorghum has also reported wider adaptability in the different environmental conditions (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. Carbohydrates, which are mostly present in sweet sorghum stalks, can be nonstructural such as sugars and starch, or structural such as cellulose, hemicellulose, and pectin substances (Anglani, 1998). The chief sugars present in sorghum kernels are the mono saccharides, glucose and fructose, the disaccharides sucrose and maltose and the tri-saccharide Raffinose. According to the kind of sugar accumulated in the stalk, it can be divided into saccharin- type of sweet sorghum and syrup-type of sweet sorghum (Anglani, 1998). Saccharin-type of sweet sorghum, which mainly, contains sucrose, can be used for refining crystal sugar. Sugar content in sweet sorghum stalk juice mostly is sucrose and invert sugar which includes, Glucose, Fructose, Maltose and Xylose (Almodares *et al.*, 2008c). Also, they reported that Mannose, Galactose and Arabinose were not detected in sweet sorghum juice. Therefore, it seems that using carbohydrates in the stalk (sucrose and invert sugar) is suitable for ethanol production for biofuel because, these carbohydrates are easily converted into ethanol. Although, ethanol can be produced from sweet sorghum grain but it needs more processing for converting it's starch to glucose that later will be converted into ethanol (Jacques *et al.*, 1999). In addition, the produced baggase after juice extraction can be used for ethanol production (Jacques *et al.*, 1999) or as animal feed (Jafarinia *et al.*, 2005). However, presently it is not economically feasible to produce ethanol from sweet sorghum baggase (Drapcho *et al.*, 2008).

Sweet Sorghum as alternate raw material for bio-ethanol

One method to reduce air pollution is to oxygenated fuel for vehicles. MTBE (Methyl tert-butyl ether) is a member of a chemicals group commonly known as fuel oxygenators (Fischer *et al.*, 2005). It is a fuel additive to raise the octane number. But it is very soluble in water and it is a possible human carcinogenic (Belpoggi *et al.*, 1995). Thereby, it should be substituted for other oxygenated substances to increase the octane number of the fuel. Presently, ethanol as an exogenous biomass fuel is considered as a predominant alternative to MTBE for its biodegradable, low toxicity, persistence and regenerative characteristics (Cassada *et al.*, 2000). Ethanol has excellent fuel properties for spark ignition internal combustion engines; for example, its high octane and high heat of vaporization makes the alcohol more efficient as a pure fuel than gasoline because ethanol is less volatile than gasoline (Bailey, 1996). Extensive experience has been accumulated with using ethanol as a pure fuel and for blending with gasoline (Wyman, 2004).Ethanol may be produced from many high energy crops such as sweet sorghum, corn, wheat, barely, sugar cane, sugar beet, cassava, and sweet potato etc. (Drapcho *et al.*, 2008).

In recent years, there has been increased interest in the utilization of sweet sorghum for ethanol production in India as its growing period (about 4 months) and water requirement (8000 m^3 over two crops) (Soltani and Almodares 1994) are four times lower than those of sugarcane (12–16 months and 36,000 m3 crop-1, respectively). The cost of cultivation of sweet sorghum is three times lower than that of sugarcane (Dayakar Rao *et al.* 2004). Like most biofuel crops, sweet sorghum has the potential to reduce carbon emissions. Further, sweet sorghum is best suited for ethanol production because of its higher total reducing sugar content and poor sugar content compared to sugarcane juice (Huligol *et al.* 2004). The presence of reducing sugars in sweet sorghum prevents crystallization and sweet sorghum cultivars have 90% fermentation efficiency (Ratnavathi *et al.* 2004a). Sweet sorghum juice is assumed to be converted into ethanol at 85% theoretical. Potential ethanol yield from the fiber is more difficult to predict (Rains *et al.*, 1993). 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 alcohols while the same amount of sorghum grain produces 372 L (Smith and Frederiksen, 2000). Sorghum is used extensively for alcohol production (Kundiyana, 1996; Bulawayo *et al.*, 1996; Smith and Frederiksen, 2000; Gnansounou *et al.*, 2005), where it is significantly lower in price than corn or wheat (Smith and Frederiksen, 2000).One ton of sweet sorghum stalks has the potential to yield 74 L of 200- proof alcohol (Smith and Frederiksen, 2000). Therefore, it it can be proved that since ethanol can be produced from both stalk and grains of sweet sorghum, it is the most suitable crop for ethanol production using for biofuel comparing to other crops such as corn or sugarcane.

Comparative economics of ethanol production by sweet sorghum and sugarcane

Stillage from sweet sorghum after the extraction of juice has a higher biological value than the bagasse from sugarcane when used as forage for animals, as it is rich in micronutrients and minerals (Seetharama *et al.* 2002). It could also be processed as a feed for ruminant animals (Sumantri and Edi Purnomo 1997). The stillage contains similar levels of cellulose as sugarcane bagasse, and therefore it has a good prospect as a raw material for pulp production. According to a pilot study by Shree Renuka Sugars Ltd., Karnataka, India, blending sweet sorghum juice up to 10% in sugarcane juice does not affect crystallization; hence it is compatible with the sugarcane industry (Huligol *et al.* 2004). Apart from these, the pollution level in sweet sorghum-based ethanol production has $1/4^{th}$ of the biological oxygen demand (BOD, 19,500 mg L-1) and lower chemical oxygen demand (COD, 38,640 mg L-1) compared to molasses-based ethanol production. Further, ethanol is a "clean burning fuel" with a high octane rating because of its low sulphates and aldehydes and existing automobile engines can be operated with Gasohol (petrol blended with ethanol) without any need for engine modifications (Ratnavathi *et al.* 2004a). Thus, from both economics and environmental protection point of view, sweet sorghum offers good prospects for ethanol production as an additional feed stock to existing distilleries.

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