Field Sprouted Damaged Sorghum Grains for Sustainable Fuel Energy Production: A Critical Review

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Abstract: Germination, or sprouting, is a common problem for grain when weather is moist during harvest or the environment is humid during storage. The most important issues in industrial ethanol production are yield, efficiency, and energy consumption. Laboratory results in terms of ethanol yield and ethanol fermentation efficiency from artificially germinated high-tannin sorghum suggest that huge potential energy savings exist in production of ethanol from germinated sorghum grain. Using germination-damaged sorghum for industrial ethanol production might benefit the producer and end user by expanding market uses of what has been historically considered a low-value commodity. Germination not only causes compositional changes in the sorghum grain but also initiates a series of biochemical and physiological changes. Intrinsic enzymes such as amylases, proteases, lipases, fiber-degrading enzymes, and phytases are activated.

Current fuel ethanol research and development deals with process engineering trends for improving biotechnological production of ethanol. This paper gives a overview of the current ethanol production processes from cereal grains and effect of sorghum grain sprouting on fermentation for sustainable fuel energy production.

Keywords: Energy, Bioethanol, Sorghum, Factors, Yield, Efficiency

1. Introduction:
Ethanol (ethyl alcohol, C₂H₅OH, melting point -114°C, boiling point 78.4°C) is soluble in water and has a density of 789 g/l at 20°C. Catalytic hydration of petroleum products (ethylene) produces a synthetic ethanol.

\[ \text{C}_2\text{H}_4 + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{CH}_2\text{OH} \]

Ethylene steam Ethanol

Many traditional chemical processes based on acidic - or base catalysed reactions for processing of agricultural products have inherent drawbacks from a commercial and environmental point of view. Non-specific reactions may result in poor product yields. High temperatures and high pressures needed to drive reactions may lead to high costs and requirement of large volumes of cooling water downstream. Harsh and hazardous processes involving high temperatures, pressures, acidity or alkalinity need high capital investment, and specially designed equipment and control systems. Unwanted by-products may prove difficult or costly to dispose of. High chemical and energy consumption, and harmful by-products have a negative impact on the environment. The use of enzymes may virtually eliminate these drawbacks within the non-food as well as within the food area. Fermentation processes for brewing, baking and the production of alcohol have been used in ancient China and Japan. The production of fermented alcoholic drinks from crops rich in starch has been practiced for centuries.

2. Bioethanol:
Bioethanol is derived from alcoholic fermentation of sucrose or simple sugars. Absolute and 95% ethanols are good solvents and are used in many industrial products such as paints, perfumes and tinctures. Bio-ethanol captures the alcoholic beverage market and a small share of vehicle fuel market. Ethanol intended to nonfood uses is made unfit for human absorption by addition of small amount of toxic or unpleasant substances such as methanol or gasoline. Bioethanol has an increased attention over the last few years, mainly due to its potential as a substitute for fossil fuels and the need to reduce global economics dependence on fossil resources. Significant advances have been made towards the technology of ethanol fermentation [Lin and Tanaka¹, 2006]. Bioethanol is a form of renewable fuel that can be produced from agricultural feedstocks such as sugar cane [Mayuri² et al., 2011], sorghum [Sheorain³ et al., 2000; Tahmina⁴ et al., 2011; Wu⁵ et al., 2007], organic and food waste (maize) [Akpan⁶ et al.,
Grain-based alcohol is more expensive to produce than molasses-based alcohol, due to the high cost of raw material and additional processing costs (for coal/steam, and enzymes). During mid-1998 in eastern Maharashtra, the cost of producing extra neutral alcohol ENA from molasses varied from Rs 13 to 16 per litre, and that from grain from Rs 21 to 27 per litre depending on raw material cost and alcohol recovery. Maharashtra Government is in favor of promoting grain-based alcohol production to create a demand for rainy-season sorghum.

Sorghum grain is one of the most important sources of carbohydrates. Carbohydrates and fibers comprise approximately 72% of sorghum grains (Wu et al., 2007). Its starch component has similar properties to corn starch, and can be used almost interchangeably. Since there are hundreds of sorghum hybrids available commercially, if these feedstocks are the option for bioethanol production, the large variations in their composition will surely affect the hydrolysis and fermentation performance (Wang et al., 2008). Thus, it is important for the ethanol industry and sorghum producers to have appropriate methods that accurately predict sorghum ethanol yields and conversion efficiencies (Zhao et al., 2009). In approximate terms, ethanol yield from sorghum grain is comparable to that from corn grain. However, in the past, factors impacting ethanol yield were less well studied for sorghum than for corn. Little research has been conducted on performance of sorghum varieties in ethanol fermentation. Zhang et al. studied the effect of genotype and location on ethanol and lactic acid production of a limited number of sorghum genotypes. Several researchers have investigated the digestibility of sorghum starch [Rooney LW and PXugfelder RL, 1986.] and sorghum protein [Zhang G, 1998, Duodu KG 2003] as related to its use in feed or food. Others have investigated the isolation of sorghum starch [Yang p and Seib PA 1995, Yang P and Seib PA 1996] and its properties [Beta T et al., 2001, Beta T et al., 2001]. The economic viability of an ethanol production facility depends on several factors, including ethanol yield, efficiency of conversion, and quality of the “distiller’s grain” (grain residue and yeast mass remaining after the fermentation process). Recently, however, sorghum cultivars with high protein digestibility and improved starch digestibility have been reported (Weaver et al 1998). By analyzing the relationship of genetics, grain component structure, molecular structure/function, and starch conversion to ethanol, factors affecting the bioprocessing of sorghum into ethanol can be studied in a better way.

### 3. Sorghum Grain as Raw Material for Ethanol Fermentation:

Sorghum on a world basis ranks fifth among the cereal grains. It is the third most important cereal crop in India after rice and wheat, grown on 16.11 million ha, with a total production of 10.68 million tonnes (Anonymous 1983). The important states with sizable acreages are: Maharashtra, Andhra Pradesh, Madhya Pradesh, Karnataka, Tamil Nadu, Gujarat, Rajasthan, Uttar Pradesh, and Haryana. Grains are a rich and cheap source of starch. Although maize is the most commonly used grain for alcohol production especially in USA, sorghum has several advantages over maize. It has higher starch compared to maize (Table 1) (Lorenz and Kulp 1991). Sorghum is grown in both kharif and rabi seasons and the kharif crop is mostly F1 hybrids, which have good fodder and grain yield.

![Comparison of composition of sorghum and maize](image)

<table>
<thead>
<tr>
<th>Component</th>
<th>Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorghum</td>
<td>Maize</td>
</tr>
<tr>
<td>Starch</td>
<td>63–68</td>
</tr>
<tr>
<td>Moisture</td>
<td>9–13</td>
</tr>
<tr>
<td>Proteins</td>
<td>9–11</td>
</tr>
<tr>
<td>Fats and oils</td>
<td>1–1.5</td>
</tr>
<tr>
<td>Crude fiber</td>
<td>1.5–2</td>
</tr>
<tr>
<td>Ash</td>
<td>1–2</td>
</tr>
<tr>
<td>Other organics</td>
<td>8–12</td>
</tr>
</tbody>
</table>

The third most important cereal crop in India after rice and wheat, and the rest comes from grains, and roots and tubers. Production of sorghum-based alcohol was not encouraged in the past keeping in mind food security, since it is the third most important food grain in India. However, with decreasing per capita consumption of sorghum and greater availability of rice and wheat, rainy-season sorghum is gaining popularity as a raw material for industrial uses. Rain-damaged or blackened sorghum could be a favorable raw material for alcohol production because of its lower market price. Maharashtra, the main producer of rainy season sorghum, regularly faces the problem of finding suitable users of blackened sorghum which constitutes 40-60% of its produce, depending on the rainfall pattern during grain maturity.
4. Current Technology for Ethanol Production using starch based raw material:

Ethanol production from grain involves milling of grain, hydrolysis of starch to release fermentable sugars, followed by inoculation with yeast. Chemically starch is a polymer of glucose. Yeast cannot use starch directly for ethanol production. Therefore, grain starch has to be completely broken down to glucose by a combination of two enzymes, viz., amylase and amyloglucosidase, before it is fermented by yeast to produce ethanol. Alcohol so produced is distilled from fermented broth. The remaining stillage is processed to produce Distillers Dried Grains DDG or DDGS. Fuel ethanol is produced from corn by either dry grind (82%) or wet mill (18%) process and majority of these biorefineries being constructed are dry grind plants (Renewable Fuel association 24 2007). A schematic overview of the process from grain to fuel alcohol is shown in Figure 1.

![Figure 1: Overview of the basic “dry grind” process of fuel alcohol production](image_url)

5. Effect of Grain Sprouting on Fermentation Performance:

Germination promotes the development of cytolytic, proteolytic, and amylolytic enzymes that are not active in dry kernels. Yan25 et al. (2009) studied the effect of germinated sorghum on ethanol fermentation and fermentation efficiency. Results from laboratory-germinated, tannin-containing grain sorghum (i.e., sorghum with a pigmented testa) showed that germination decreased tannin content, improved sorghum fermentation performance, shortened fermentation time. To a certain degree, germination of feedstocks may not be negative for ethanol fermentation. Germination causes compositional changes in the sorghum grain and also initiates a series of biochemical and physiological changes. Intrinsic enzymes such as amylases, proteases, lipases, fiber-degrading enzymes, and phytases are activated; this disrupts protein bodies and degrades proteins, carbohydrates, and lipids to simpler molecules, which increases digestibility of proteins and carbohydrates in the kernel and makes nutrients available and accessible for enzymes. Free amino nitrogen (FAN) is an essential nutrient for yeast growth during fermentation. Recent research has found that ethanol yield and conversion efficiency significantly increased as FAN increased in laboratory-germinated and field-sprouted grain sorghum. Yeast can only utilize FAN and short peptides, not large intact proteins. Table 2 shows chemical composition of the five field-sprouted samples and the control (non-sprouted). Field sprouting damaged starch granules, protein matrices, and cell walls in sorghum kernels, consequently decreasing kernel hardness, kernel weight, and kernel size. Field sprouting also changed the chemical composition and pasting properties of field-sprouted grain sorghum, which could shorten fermentation time without decreasing ethanol yield. Field-sprouted grain sorghum had relatively high FAN content. The FAN provided efficient buffering capacity and optimal yeast performance, and field sprouted sorghum had a more rapid fermentation rate than non sprouted sorghum. The FAN in the non-sprouted sample was lower than that in the sprouted samples even though the non-sprouted sorghum sample had the highest protein content. Enzymatic degradation of protein by activated intrinsic proteases during sprouting resulted in an increase in FAN contents and short peptides, which accounted for the significant increase in FAN levels of field-sprouted sorghum samples.
6. Conclusion: This review concludes that there is vast scope of ethanol production from biodegradable food grains in this era of energy crises. In ethanol production industries hundreds of sorghum hybrids are used, there is variation in fermentation quality among these hybrids. This shows the importance for ethanol industries and sorghum producers to have proper methods to predict their ethanol yield as well as conversion efficiencies. Review of scholars work indicates that genetically improving the quality of grain sorghum for ethanol production increases the utilization of sorghum for ethanol production. Sprouted sorghum had a more rapid fermentation rate than non sprouted sorghum. Sprouted grain sorghum had relatively high free amino nitrogen content. Grain damaged by sprouting may lose value for food applications but may not affect ethanol production and final ethanol yield. Thus, using weathered and/or sprouted sorghum from regions affected by unusually high moisture events during grain fill and harvest may provide an opportunity for ethanol producers to maintain ethanol production efficiency, while shortening processing time. This could offer sorghum producers an opportunity to receive a premium, or at least a fair market value for sorghum when such environmental events occur. Hence from the above review of literature it is evident that there is a vast scope of ethanol fermentation using damaged food grains. After the study of factors affecting ethanol fermentation using food grains it is possible to control the operating variables like processing temperature, enzyme concentration and time. These governing parameters would definitely enhance the bioethanol production rate as well as utilization of germinated damaged food grains.

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8. References:

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### Table 2: Physiochemical characteristics of sorghum grains

<table>
<thead>
<tr>
<th>Sorghum samples</th>
<th>Chemical composition (% wb)</th>
<th>FAN (mg/l)</th>
<th>α-amylase activity</th>
<th>Kernel weight (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MC</td>
<td>Ash</td>
<td>Protein</td>
<td>Fiber</td>
</tr>
<tr>
<td>Control</td>
<td>10.38</td>
<td>1.62</td>
<td>11.59</td>
<td>1.15</td>
</tr>
<tr>
<td>Variety1</td>
<td>12.28</td>
<td>1.18</td>
<td>6.66</td>
<td>2.12</td>
</tr>
<tr>
<td>Variety2</td>
<td>12.97</td>
<td>1.19</td>
<td>7.02</td>
<td>2.24</td>
</tr>
<tr>
<td>Variety3</td>
<td>11.92</td>
<td>1.26</td>
<td>7.60</td>
<td>2.07</td>
</tr>
<tr>
<td>Variety4</td>
<td>12.71</td>
<td>1.10</td>
<td>7.27</td>
<td>1.95</td>
</tr>
<tr>
<td>Variety5</td>
<td>12.52</td>
<td>1.15</td>
<td>6.96</td>
<td>1.91</td>
</tr>
</tbody>
</table>

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FAN contents in the mashes of sprouted sorghum samples will further increase during the slurry and liquefaction process. Also, α-amylase activity in the non-sprouted control was lower than that in sprouted grains sorghum. The diverse values of FAN and α-amylase activity also revealed that samples had experienced different degrees or durations of field sprouting. All field-sprouted samples had high starch content.