Beer Brewed from Sorghum

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Beer is a complex beverage system despite being made up of only four ingredients: yeast, water, hops, and malted grain. Typically, malted barley is used as the primary grain source for brewing, however alternative grains/pseudo-grains like sorghum are gaining popularity. However, the use of sorghum in beer manufacturing does have its issues, which are largely due to its low amylolytic activity (which is insufficient for complete saccharification), high gelatinization temperature, and low free amino content. Sorghum malt has a higher concentration of alpha-amylase and a lower concentration of beta-amylase compared to malted barley. Due to the reduced enzymatic activity of sorghum this deficiency can lead to insufficient production of fermentable sugars, high dextrin content, and increased viscosity. Due to sorghum's higher gelatinization temperature, the hydrolysis of sugars into fermentable sugars is only partially completed. Thus, resulting in fewer fermentable sugars for the yeast to metabolize for the production of ethanol, and volatile and semi-volatile compounds.

sorghum malt GC-MS

1. Overview

There is currently an increased demand for foodstuffs that are classified as gluten-free including beer. Beer produced using gluten-free grains has a distinct flavor profile that differs greatly from that of beer produced from gluten-containing grains. The chemical difference between beers made from these two different grain sources has been explored and some key differences have been identified. Here malt sources containing gluten (barley) and malt without gluten (sorghum) were used to determine which compounds are statistically different based upon their concentrations. A total of 14 (7 barley and 7 sorghum) small-batch beers were made from malt extract. The aroma profile was sampled using SPME with chemical separation and identification and quantification using GC-MS. As expected, the differences were not the result of unique compounds but compounds present in differing amounts. A total of 17 compounds were found to be present in beer brewed from both extracts but in amounts that were highly significantly different.

2. Sorghum and Beer

Beer is one of the oldest fermented beverages currently being sold on the market. It is also one of the most widely consumed alcoholic beverages in the world [1]. Beer is traditionally brewed using malted barley. Unfortunately, people with known gluten-sensitivities or diagnosed with celiac disease (CD) are unable to drink conventional beer. For a naturally gluten-free beer, brewers can use pseudo-cereals or gluten-free grains such as rice, corn, sorghum, or millet. These grains are distantly related to wheat, rye, and barley therefore these products are considered safe to consume by individuals who have CD or who are gluten intolerant [2].

Those who follow a gluten-free diet still want to have the option of selecting from the highest quality of gluten-free products available to them. This demand for higher quality gluten-free products is the reason why the gluten-free product market is estimated to be worth more than 7.59 billion USD [3]. Strict adherence to living a gluten-free lifestyle can be extremely difficult and often compromising the quality of life. People will oftentimes forgo their strict diets and accept the side effects of consuming gluten to take part in popular activities such as eating out and consuming a beer [4][5][6]. Although one can argue that beer is not required and does not necessarily play an important role in providing someone with their necessary nutrients, however, a person’s diet does encompass a number of food items that provide more than just the physiological need for nutrients. Beer is one of these products that is consumed throughout the world on a large scale. Therefore, it is important that individuals with CD are also able to safely consume and purchase good-tasting gluten-free beers, due to the impact it would have on improving a person’s well-being and ability to participate in social life [2].

Sorghum (*Sorghum bicolor* (L.) Moench) is a tropical cereal grown throughout the world in India, China, Brazil, Africa, Australia, and the United States [7]. The use of sorghum as a brewing material has been around for thousands of years in a number of different countries throughout Africa [8]. By the late 1980s, Nigeria was manufacturing clear sorghum beer to mimic traditional lager and stout styles as opposed to the traditionally opaque beer of Africa [9]. Nigeria produces in excess of over 18 million hectoliters of beer annually, much of which is produced using sorghum grains [10]. The use of sorghum as a brewing substrate has grown in popularity throughout Africa as well as the United States. The increase in popularity within the United States has to do more with people following a gluten-free diet and brewers wanting to accommodate that sector of the market.

Beer’s flavor plays a significant role in consumers’ acceptance or rejection of the product. The flavors produced during the fermentation process are the result of a number of complex reactions between a wide variety of chemical compounds [11]. Beer consists of a number of different flavor compounds such as alcohols, esters, aldehydes, ketones, esters, carboxylic acids, organic acids, sulfur compounds, amines, phenols, and all of these different compounds at their varying levels of concentration will influence the aroma and flavor of the final product [12][13]. A number of these volatile compounds play an important role in the overall beer’s flavor, while others will merely build up the background flavor of the product [14]. These compounds are derived from a combination of the fermenting grain, yeast metabolism, and the addition of bittering hops.

3. Conclusions

Beer is a complex beverage system despite being made up of only four ingredients: yeast, water, hops, and malted grain. Typically, malted barley is used as the primary grain source for brewing, however alternative grains/pseudo-grains like sorghum are gaining popularity. However, the use of sorghum in beer manufacturing does have its issues, which are largely due to its low amylolytic activity (which is insufficient for complete saccharification), high gelatinization temperature, and low free amino content [15][16]. Sorghum malt has a higher concentration of alpha-amylase and a lower concentration of beta-amylase compared to malted barley. Due to the reduced enzymatic activity of sorghum this deficiency can lead to insufficient production of fermentable sugars, high dextrin content, and increased viscosity [17][18]. Due to sorghum's higher gelatinization temperature, the hydrolysis of sugars into fermentable sugars is only partially completed. Thus, resulting in fewer fermentable sugars for the yeast to metabolize for the production of ethanol, and volatile and semi-volatile compounds [19].

Wort, is composed of a number of different nitrogenous sources, however, yeast is only able to utilize the individual units (amino acids) and smaller peptides [20]. Free amino nitrogen is necessary for yeast health, growth, viability, vitality, fermentation efficiency, and beer stability and quality [21]. Optimum FAN levels can vary from yeast strain to yeast strain, batch to batch, and wort sugar levels and type. The general consensus is that anywhere from 100–140 mg L^{-1} FAN is required for a satisfactory fermentation, however, those values can vary based upon the fermentation matrix (wort vs. must) as well as the wort's starting gravity [22][23]. As expected, FAN levels will vary between malted barley and sorghum. Sorghum malts tend to have lower FAN levels as well as lower levels of valine [16][24]. This can lead to the production of higher levels of vicinal diketones (diacetyl) [25].

Research has shown that the initial FAN levels can have either a positive or negative effect on the development of certain aroma compounds produced by the yeast during fermentation [26]. While the concentration of fermentable sugars is important and can be a limited factoring, it is likely that for this experiment the FAN levels could have potentially reduced the yeasts' ability to produce a number of aroma active compounds [15]. If FAN levels are too low the yeast will produce lower concentrations of esters. Excessive levels of FAN can result in the overproduction of off-flavors such as diacetyl and higher (fusel) alcohols [27]. Due to the less than ideal starting FAN values in the sorghum wort, it is suspected that the FAN concentration played a negative role in the overall concentration of esters produced by the yeast. Despite not utilizing enzymes to help increase mash extraction efficiency, it would have not helped in this case. Malting and processing techniques will play a greater role in the overall concentration of FAN within the wort than in the utilization of enzymes [28]. Key differences between malted barley and sorghum could be associated with the steeping regime and the sorghum cultivar used to develop the LME [29].

Beer flavor is the result of a mixture of volatile, semi-volatile, and non-volatile compounds and their interaction with each other. The formation of flavor compounds is a complex and critical process that plays an important role in the quality of beer [30]. A number of flavor compounds have been identified in beer such as alcohols, esters, carbonyls, organic acid, sulfur compounds, amines, and phenol. A number of volatile compounds will contribute to the overall flavor and aroma of the final product, with other compounds playing a minor role in enhancing the flavor of the product [31].

The volatile and semi-volatile compounds produced during the fermentation process are the result of the yeast strain selected, the wort composition, and the brewing process [19]. The use of gas chromatography coupled with mass spectrometry (GC-MS) for the identification and quantification of the volatile and semi-volatile compounds found in beer to predict the flavor and aroma compounds is a common as well as established practice [32].

Long-chain carboxylic acids can contribute fruity, cheesy, and fatty odors and can also contribute to bitterness, astringency, and potentially rancidity. Alcohols contribute to the strong and pungent smell and taste of beer. The higher-order alcohols are important precursors of flavor esters, and the presence and control of these alcohols can have an impact on the production of these flavor esters. Esters contribute fruity flavors and play an important role in balancing beer flavors. Esters contributed to the largest class of compounds in this study.

These mainly derive from yeast metabolism and not from the original malted grains and the majority of these compounds have been reported in previous studies of beer [14][33][34]. The compounds are a mixture of pleasant and unpleasant aromas, with many adding fruity or sweet character to the aroma, but several off aromas were noted. Compounds such as 1-octanol, and ethyl octanoate have unpleasant aromas from aromatic to fatty. The addition of these at levels that are at or above the perception threshold would certainly reduce the consumer experience. As the concentrations determined in this study are approximate based on an assumed response factor no relation to the perception thresholds could be determined. However, with the compounds being highly statistically different and primarily from yeast metabolism, changes in yeast strains could influence the relative concentrations of these key compounds.

The common flavors associated with malted barley are largely due to the roasting process [35]. Unlike malted barley, less is known about the compounds responsible for sorghum's flavor. There has been some research looking at the impact malting germination temperature has on fusel alcohol production for sorghum beers [30], but there is limited published data on the overall profile of sorghum brewed beers. Ma et al. 2016 is one of the few published papers looking at the volatile and semi-volatile compounds found in beer focusing on extruded and unextruded white sorghum used as a brewing adjunct. It should also be noted that utilizing 100% sorghum as your grain source for the production of beer could result in impaired yeast growth as well as impaired enzymatic activity [15], which is why some brewers will adjust their grain bill to incorporate malted barley as a way to overcome these issues [30]. Einfault (2020) looked at three different yeast strains to evaluate their fermentation activity and sensory characteristics. However, it is difficult to compare the two studies, since they focused on sixteen specific compounds, unlike this study that focused on complete characteristics. It also should be noted that Einfault's study utilized SafAle™ WB-06, which is a variant of *S. diastaticus* used to produce a high attenuating German Wheat beer. This strain of yeast is known for its subtle ester and phenol notes [36]. This particular study used SafAle™ US-05 American ale yeast, traditionally used for its neutral and clean-producing flavor profile.

Even though a number of the same chemical (esters, alcohols, aldehydes, etc.) compounds are found in malted barley and sorghum-based beer, the overall concentrations of these chemical groups will vary due to differences in the chemical composition (Total nitrogen, FAN, sugar concentration, etc.) of the grains used. These differences in the composition of barley and sorghum influence the yeast's ability to metabolize these metabolites for secondary metabolite production of the wort [20]. The final sensory profile of the beer is not solely reliant upon the volatile and semi-volatile compounds produced by the yeast, but by the combination of the hops used and their addition to the boil, along with the grain source as well as the compounds produced by the yeast during the fermentation process [15].

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