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Alternatives to malt in brewing

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Background: Due to the competitiveness of the beer market, breweries are under pressure to lower the cost of beer production. They have also attempted to widen their offers by developing new, innovative products to meet consumer demand. To achieve these goals, they have increasingly replaced malt with various less expensive adjuncts. It is estimated that up to 85–90% of beer worldwide is now produced with adjuncts.

Scope and approach: The use of adjuncts may cause negative as well as positive changes to the quality of the final product. It is therefore important to understand the impact of particular adjuncts on the different properties of beer in order to ensure appropriate use. In this review, both the positive and negative consequences are discussed of the partial replacement of malt with other carbohydrate sources during beer production.

Key findings and conclusions: Novel analytical methods and research developments have shed new light on the impact of adjuncts on beer characteristics. Appropriately chosen adjuncts can contribute to lighter colours, improved colloidal or foam stability and prolongation of beer shelf-life. The flavour profile can also be changed by altering the sugar and amino acid spectra in wort. However, negative consequences may also result from the use of adjuncts. With appropriate processing and the application of commercial enzymatic preparations during wort and beer production these threats can be minimized.

1. Introduction

Beer is one of the oldest known beverages in the world, and is still a staple low-alcohol product. The world beer market is extremely competitive, and has become more so in recent years – as Europe, North America and Japan have witnessed a decrease in beer sales, partially associated with the expansion in these markets of lager beer. In response, many breweries have attempted to widen their offers by developing new, innovative products to meet consumer demand (Carvalho et al., 2009; Hager, Taylor, Waters, & Arendt, 2014; Harasym & Podeszwa, 2015; Yeo & Liu, 2014). They have also come under pressure to produce consistently high quality beer at lower cost. As a result, brewers have increasingly replaced malt with various less expensive adjuncts.

Up to 85–90% of beer in the world is now produced with adjuncts (Annemüller & Manger, 2013, pp. 1–80). However, there are wide variations in the use of adjuncts on different continents. In European countries, between 10 and 30% of malt is replaced by unmalted materials, in the United States and Australia 40–50% or more, while in Africa the figure stands at between 50 and 75% (Annemüller & Manger, 2013, pp. 1–80). Climatic conditions are not favourable to barley crops in Africa (Taylor, Dlamini, & Kruger, 2013). The substitution of barley malt with unmalted grains cultivated domestically is a way to limit the need to base beer production on expensively imported barley malt, so reducing the cost of raw materials (Goode & Arendt, 2006). These grains are most often used unmalted, since climatic conditions in Africa are not very suitable for malting either (Agu & Palmer, 2013; Holmes, Cahill, Smart, & Cook, 2013; Uvere, Ngoddy, & Nwankwo, 2014). On other continents too, the use of unmalted grains reduces the need to process poor quality malt, which may be affected by adverse weather conditions in particular years, and can even mitigate shortages of malt on the world market (Goode, Wijngaard, & Arendt, 2005). Indigenous cereals are usually used as adjuncts, supporting local agriculture. Sorghum is the most common adjunct in Africa, rice in Asia, corn in America. In Europe, barley and corn are the most often used adjuncts (Annemüller & Manger, 2013, pp. 1–80; Zhu, Ma, Li, & Li, 2015).

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The inclusion of even a little unmalted raw material in the grist can alter the sensory properties of beer. Thus, it is possible to obtain a product of new flavour and aroma without having to change the production line (Kordialik-Bogacka, Bogdan, & Diowksz, 2014; Piddocke, Kreisz, Heldt-Hansen, Nilsen, & Olsson, 2009; Yeo & Liu, 2014). It is estimated that a 30% substitution of malt with unmalted corn allows for an 8% reduction in the cost of beer production (Poreda, Czarnik, Zdaniewicz, Jakubowski, & Antkiewicz, 2014). The addition of sugar syrups or granulated sugar, meanwhile, provides a simple way to increase wort gravity. High-gravity fermentation is more cost-effective and is now common practice in the brewing industry (Piddocke et al., 2011). The use of adjunct can also influence the price of the final product due to tax regulations, such as in Japan where liquor tax is calculated according to malt usage (Braun & Dishman, 2006; Goode & Arendt, 2006). In Germany, Switzerland and Greece, where the German Purity Law (Reinheitsgebot) is applicable, beer can only be produced from malt, water, hops and yeast and other sources of starch and sugar are prohibited. Nevertheless, it is nowadays possible to produce beer by taking even raw barley as the only source of extract (Aastrup, 2010; Heldt-Hansen, Elvig, Schönenberg, & Kreisz, 2011; Steiner, Auer, Becker, & Gastl, 2012). Supplementation of the mashes with exogenous enzymatic preparations is necessary to break down the starch, proteins and cell wall components in the grains (Steiner et al., 2012).

The aim of this review is to discuss both the positive and negative consequences of the partial replacement of malt with other carbohydrate sources during beer production.

2. Malt substitutes

The definition of an adjunct has changed over the years. Currently, adjuncts are described as sources of extract other than malt (Atnafu & Abebaw, 2015; Briggs, Boulton, Brookes, & Stevens, 2004, pp. 34–200). Adjuncts can be divided according to their state of matter, into solids and liquids. The first group comprises unmalted cereals such as barley, corn, rice and (of lesser importance) wheat, oats, sorghum, rye, and triticale, together with unmalted pseudocereals (buckwheat, amaranth, quinoa), cassava, teff and granulated sugar (sucrose) (Annemüller & Manger, 2013, pp. 1–80; Goode & Arendt, 2006). All except for granulated sugar require being hydrolized in the mashing process with malt or exogenous microbial enzymes. For this reason, they are called **mash vessel adjuncts**. Liquid adjuncts include sucrose-based syrups, derived from sugar cane or sugar beet, and hydrolyzed starch syrups (wort extenders), as well as malt extracts and syrups obtained from hydrolyzed cereals (wort replacements). Apart from carbohydrates, the latter contain nitrogenous compounds and minerals and their composition is similar to that of brewing wort. Malt extracts, supplied as hopped and unhopped, are popular among home brewers and micro-breweries. Liquid adjuncts and granulated sugar contain soluble sugars and can be added to boiling finished wort. They are therefore called **copper or kettle adjuncts**. These are commonly used to produce high-gravity worts, which serve to increase the capacity of the brewhouse and as a result the production capacity of the whole brewery. Their application also enables wort fermentability to be adjusted easily (Piddocke et al., 2009; Piddocke et al., 2011). Sucrose is used both in solid and liquid forms, as dissacharide or invert sugar after hydrolysis (a mixture of glucose and fructose). Nevertheless, concentrated solutions of sugar tend to crystallize, which requires warm handling and storage, at 40–50 °C (Briggs et al., 2004, pp. 34–200).

Iodine-negative starch hydrolysates from corn, wheat or rice are produced off-line by enzymatic and/or acid hydrolysis and can have a similar sugar composition to malt worts. These are prepared from the endosperm of grains following the separation of germs and bran (Annemüller & Manger, 2013, pp. 1–80; Szwed, Tomaszewska-Ciosk, & Blazewicz, 2014). A wide variety of syrups may also be used, with different compositions of fermentable (glucose, maltose, maltotriose) and non-fermentable (maltotetraose and higher oligosaccharides) sugars, depending on the degree of starch hydrolysis they have undergone. Syrups are often categorized according to their dextrose equivalent value (DE value), which corresponds to the percentage content of reducing sugars, calculated as glucose (although this does not provide a full picture of the sugar spectrum in the syrup and consequently of the fermentability of the supplemented wort) (Stewart, 2006). Maltose-rich syrups are preferable to glucose-rich syrups. In worts abundant in glucose, yeasts have difficulty adapting to metabolize maltose and maltotriose, which slows or halts fermentation. Nowadays, starch-derived syrups are widely used by large-scale breweries (Piddocke et al., 2009). Syrups allow to increase the strength of wort with no additional investment in the brewery. Moreover, these adjuncts enable to overcome problems with heterogeneity of raw grains, by ensuring the consistent composition of the wort and beer. They also reduce the space required to store cereal raw materials. Use of syrups or sugar can provide savings in terms of energy and materials. When syrups or sugar are used, the mash can be thinner, making extraction and separation of the wort from raw materials easier. Due to the lower amounts of sludge in pitching wort, there is also reduced soiling of yeast cells during fermentation.

Mash vessel adjuncts include products which are: (1) not pre-cooked but can be directly mixed with grist, such as wheat flours, (2) pre-cooked outside the brewery, such as flaked maize or rice grits, micronized and torrefied whole grains, flaked wheat or barley, and flaked pearl barley, (3) require cooking in the brewery during mashing, such as rice, maize or sorghum grits and flours or refined starches from these materials (Meussdoerffer & Zarnkow, 2009). This division is associated with the different gelatinization temperatures of starches derived from various sources. In the case of adjunct starch (for example rice starch) which gelatinizes at temperatures higher than those at which malt enzymes are active, prior starch gelatinization is necessary before the adjunct can be mixed with the malt mash (Glatthar, Heinisch, & Senn, 2005; Goode et al., 2005; Meussdoerffer & Zarnkow, 2009; Poreda et al., 2014). This requires a cereal cooker, an additional vessel in the brewhouse, if infusion mashing is performed. When cooking grits (in particular rice), it is preferable to use exogenous α-amylase or a portion of highly enzymatic, ground malt. Gelatinization of raw cereals can also take place in the mash vessel before the introduction of the malt grits with water. Nevertheless, this procedure prolongs wort production (Krottenthaler, Back, & Zarnkow, 2009; Meussdoerffer & Zarnkow, 2009).

The use of rice is now mostly limited to Asian countries, due to its high price. Broken grains, a by-product of rice grown for human consumption, are used. Before further processing, de-husking and degerming are required (Stewart, 2006). A mixture of different varieties is usually delivered, which results in considerable fluctuation in terms of starch gelatinization temperature and the duration of wort separation. Rice is considered to give beer a neutral, dry, light and clean flavour (Pliansrithong, Usansa, & Wanapu, 2013). A fuller flavoured beer is obtained with corn. Before corn can be processed into grits or flakes for brewing purposes, the oil-rich germs have to be removed (Annemüller & Manger, 2013, pp. 1–80; Meussdoerffer & Zarnkow, 2009; Yeo & Liu, 2014). When a brewery uses a lauter tun, there cannot be excessive amounts of rice or corn in the grist, because the rice used is de-husked and corn grits do not contain husks, which serve as a filter layer during lautering (Meussdoerffer & Zarnkow, 2009). In the case of wheat, which is rich in pentosans which increase viscosity, coarse grinding